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NOTES ON
PERMANENT-WAY MATERIAL, PLATELAYING, AND POINTS AND CROSSINGS.

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NOTES ON

PERMANENT-WAY MATERIAL

PLATELAYING AND POINTS & CROSSINGS

WITH A FEW REMARKS ON

SIGNALLING AND INTERLOCKING

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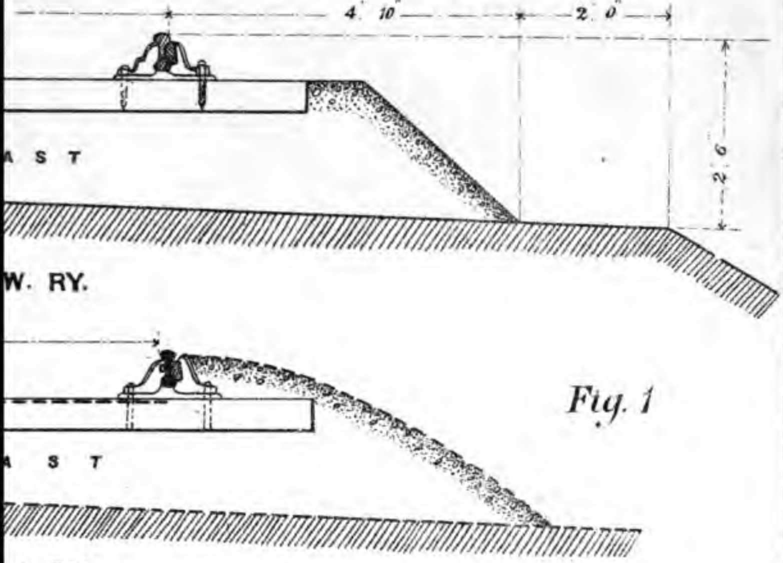

Fig. 1

FRONTISPIECE

NOTES ON

PERMANENT-WAY MATERIAL

PLATELAYING

AND

POINTS & CROSSINGS

WITH A FEW REMARKS ON

SIGNALLING AND INTERLOCKING

BY

W. H. COLE, M. INST. C.E.

EXECUTIVE ENGINEER, PUBLIC WORKS DEPARTMENT, INDIA

"MENTE MANUQUE"

SECOND EDITION

London:
E. & F. N. SPON, 125 STRAND
New York:
SPON & CHAMBERLAIN, 12 CORTLANDT STREET
1896

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PREFACE

TO

THE SECOND EDITION.

I HAVE no reason to regret having specially addressed the first edition of these 'Notes' to Permanent-way Inspectors; its dedication to them was the natural conclusion of my intention to write a text-book mainly for their use. I have to thank several of them for suggestions contained in letters which combined the most candid criticism with the friendliest appreciation of my first essay. To the Permanent-way Inspector I dedicate this second edition also.

For six months, in 1891–92, I was placed on special duty, under the orders of the Secretary of State for India, to report on certain subjects in relation to British and French railways. Among these were 'Permanent Way' and 'Signalling and Interlocking.' My examination of the former—in which I owe much to the courtesy of the engineers on various English and Scotch railways—has better enabled me to cover wider ground (although I have purposely confined myself to representative types) in the descriptions (Chapter I., Arts. 22–34) and sketches (Figs. 1–14) of permanent way. My study of the latter was chiefly pursued in the works of the great signalling firms, who gave me all possible information and assistance; and Chapter V. is practically a reprint of the introductory note to the detailed Report which I submitted to the Government of India on this subject. It has had, however, the advantage of being since corrected by Messrs. MACKENZIE and HOLLAND, of Worcester, to whom I am especially indebted.

Articles 35–39, on 'Platelaying,' have been rewritten.

In the chapter on 'Points and Crossings' I have worked out formulæ (30*a*) and (31*a*) for crossovers where the two crossings have not the same angle. The solution of the case of a crossover between two parallel curved roads has been sufficiently indicated. Mr. R. EGERTON, Executive Engineer, furnished me with the exact formulæ (24), (24*a*), (26), and (26*a*) for determining the angle of a crossing; and other additions will be noticed, especially in the articles on 'Gathering Lines' and 'Three-throw Points and Crossings,' and the special approximate formulæ (5*b*), (7*b*), (10*a*), (12), (23), (24*b*), (26*b*), and (29), applicable to eight different gauges. These last (in some cases again simplified) also appear in Chapter IV. on 'Simple Rules.'

The Tables of Cant required on curves have been made out for seven gauges. Table X., of Middle Ordinates of Curved Rails, has been added. Table XI., of Numbers, Angles, and Factors, will be found useful in applying the formulæ for points and crossings. Tables XII.–XIX., of Numbers, Radii, Curve-leads, Switch-leads, Leads, Turnouts and Crossovers, have now been worked out (in accordance with a friendly suggestion) for eight gauges—the 5′ 6″, 5′ 3″, 5′ 0″, 4′ 8½″, 3′ 6″, metre, 3′ 0″, and 2′ 6″; the half numbers—5½, 6½, 7½, &c.—have been inserted; and the figures extend (except in the last Table) from 1-in-5 to 1-in-16 crossings. The calculations for these were got out at various times, chiefly on board ship and on railway journeys. They can be checked by the formulæ on page 114; and I shall be much obliged if readers who detect errors will inform me through the publishers. The Graphic Diagram (Fig. 37) may be applied to any of six gauges, for each of which a scale to be used is given. In Table XXII. I have selected certain Standard Dimensions which should be known to all railway engineers and inspectors in India.

Finally, I take this opportunity of thanking Mr. J. R. BELL (now Consulting Engineer for State Railways to the Government of India) for revising the proofs of the first edition, and Mr. F. WOLLEY-DOD (Deputy Consulting Engineer for State Railways to the Government of India) for similarly going carefully through the sheets of the second edition.

W. H. C.

CALCUTTA: *September* 1895.

PREFACE

TO

THE FIRST EDITION.

THE Permanent-way Inspector of to-day—so far as my knowledge of him goes—is not merely that vague product, a "practical man"; he does not necessarily prefer guesswork to certainty; he has *not* a supreme contempt for a simple and intelligible mathematical method; he has *not* a serene confidence in the fallible process of "putting it in by the eye"; and he is not one jot less practical than the platelayer of the old school, although he has had the advantage of a better education. To him, then, I dedicate this little book.

The first chapter deals with the Material which the platelayer has to work with. While on furlough in 1885 I was engaged for some months in passing material for the War Office, and so had constant opportunity of observing the processes of manufacture which I have briefly described. The inspection and test reports, I may add, are quotations from my own papers.

In the second chapter I have described the actual operations of Platelaying, both as regards construction and maintenance; and for assistance in this portion I am greatly indebted to Inspector CAMPION and several other friends, both Engineers and Platelayers.

The third chapter treats of Points and Crossings. Upon this subject Donaldson is, without question, the great authority. But simplifications of his treatment follow at once from the measurement of the gauge from inside edge to inside edge of rail-head, instead of from centre to centre of rail, since the width of the upper table of the rail disappears from all terms of the calculation and only affects the clearance. Donaldson, again, expresses the inclination of a crossing in terms of the

ART. PAGE
31. Double-headed, Bull-headed, and Flat-footed rails compared .. 35
32. Longitudinal and Transverse Wooden Sleepers compared .. 36
33. Metal and Wooden Sleepers compared 37
34. Points and Crossings 41

CHAPTER II.

PLATELAYING.

35. Division of Labour in Platelaying 45
36. Material Gangs 45
37. Linking-in Gangs 46
38. Number and Distribution of Workmen 49
39. Lifting and Packing Gangs 57
40. Duties of a Permanent-way Inspector 57
41. Duties of a Sub-inspector 59
42. Maintenance Gangs 59
43. Duties of a Mate or Ganger 59
44. Duties of the Wrenchman or Keyman 60
45. Platelayers' Tools 61
46. Maintenance of Rails 63
47. Fishing the Rails. Expansion 64
48. "Creep" or "Travel" of Rails 67
49. Maintenance of Wood Sleepers 69
50. Lifting, Packing, and Boxing 72

ART. PAGE
61. First Method. Radius of Crossing 90
62. Second Method. Radius of Crossing 90
63. Curve-lead 91
64. Switch-lead 92
65. Second Method. Lead of Crossing 93
66. Approximate Formulæ for Leads 93
67. Curves of Contrary Flexure 95
68. Curves of Similar Flexure 96
69. Lead of Crossing Constant 97
70. To Determine the Crossing 98
71. Modification of the Lead in certain cases 100
72. Turnouts and Crossovers 102
73. Gathering Lines 106
74. Three-throw Points and Crossings 108
75. Triangles 111
76. Crossing more than one Line; Diamond Crossings 112
77. Tables 113

CHAPTER IV.

SIMPLE RULES.

78. To set out a Curve by Offsets 116
79. To set out a Diversion from a Straight Line 117
80. To find the Radius of a Curve 119
81. To find the Cant required on a Curve 119
82. To find how much a Rail should be bent to suit a Curve .. 120
83. To find the Number of a Crossing 121
84. To find the Radius of a Crossing 121
85. To find the Curve-lead of a Crossing 121
86. To find the Switch-lead of a Crossing 122
87. To find the Lead of a Crossing 123
88. To find the Crossing required in any case 123

CHAPTER V.

SIGNALLING AND INTERLOCKING.

89. Remarks on Signalling and Interlocking 126

TABLES, Etc.

PAGE
I. Report on Steel Rails 133
II. Tensile Tests of Steel Rails and Sleepers 134
III.-IX. Tables of Cant for different Curves and Speeds on the 5′ 6″, 5′ 3″, 5′ 0″, 4′ 8½″, 3′ 6″, Metre, and 3′ 0″ Gauge.. 135-141
X. Table of Middle Ordinates for Rails of usual lengths laid on Curves of different radii 142
XI. Points and Crossings.—Table (common to all Gauges) of Numbers, Angles, and numerical values of Factors and Terms which appear in many of the Formulæ .. 143
XII.-XIX. Points and Crossings.—Tables of Numbers, Radii, Curve-leads, Switch-leads, and Leads; Turnouts and Cross-overs; for the 5′ 6″, 5′ 3″, 5′ 0″, 4′ 8½″, 3′ 6″, Metre, 3′ 0″, and 2′ 6″ Gauges 144-158
XX., XXI. Points and Crossings.—Tables of Numbers, Angles, Radii, Curve-leads, and Leads; Turnouts and Cross-overs; for the old and new standard Crossings in use on Indian State Railways of the 5′ 6″ and Metre Gauge 159-160
XXII. Certain Standard Dimensions to be observed in Railways in India 161-164

NOTES ON
PERMANENT-WAY MATERIAL,
PLATELAYING, AND POINTS & CROSSINGS,
WITH A FEW REMARKS ON
SIGNALLING AND INTERLOCKING.

CHAPTER I.

PERMANENT-WAY MATERIAL.

1.—Definition of Permanent Way.

The permanent way consists of rails, sleepers, and fastenings, and the term is used to distinguish the finished and permanent railroad from temporary lines laid down during construction for the carriage of material, &c.

The rails are laid to gauge, i. e. at a certain distance apart; their ends are fished together with plates and bolts; and they rest—either in chairs, on bearing-plates, or directly—upon sleepers, the flat-bottomed rail (with or without bearing-plate) being held down to the sleeper by dog-spikes, wood-screws, or fang-bolts with clips, and the chair, in which the bull-headed or the double-headed rail rests, being secured to the sleeper by solid oak trenails, by wrought-iron spikes, by fang-bolts, or by hollow trenails into which spikes are driven.

The sleepers are bedded and packed in ballast, which is spread upon the formation of the bank or cutting.

2.—Ballast.

The ballast, forming the immediate foundation and support of the permanent way, should be of a material clean, hard, and sufficiently bindable, yet loose enough to admit of free drainage.

Stone, brick, slag, or kunker, broken sufficiently small to pass in any direction through a ring 2½ or 3 inches in diameter, sharp clean gravel, or sand, is the most usual material.

On the London and North-Western Railway slag is considered to be the best of ballast; nothing will grow in it, there is little dust, and it does not fly when packed.

Sand, covered with a top dressing of brick or stone to keep down the dust, forms a fair packing for metal sleepers, but small, clean gravel is better.

That portion of the ballast which is not actually packed, but lies on the top or is loosely filled in, is called the boxing.

When an estimate is to be cut down, probably the first thing to be sacrificed is ballast. This will frequently be found to be the most short-sighted economy. Even if it be expensive, good and sufficient ballast will more than justify its provision, as a rule, by the saving in maintenance of way—both in decrease of labour and increase in life of material—and in the ultimate effect upon the rolling-stock.

3.—Iron and Iron Ores.

In one form or another iron constitutes the material of rails, fish-plates, chairs and fastenings,—and sometimes of sleepers and keys.

In a chemically pure state iron possesses no practical value, and is merely interesting from a scientific point of view.

Its qualities as a constructive material depend upon the more or less complete elimination of sulphur, phosphorus, silicon, and other impurities, and upon the admixture of very small proportions of carbon and manganese.

Iron is obtained in its first condition—that of pig iron—by smelting certain ores in a blast furnace with coke and lime.

Of workable ores, the oxide class includes magnetic iron ore, red hæmatite and brown hæmatite, while the carbonate class is found in the forms of spathic iron ore and clay ironstone.

Swedish iron is obtained from magnetic ore. Red hæmatite is found in Lancashire and Cumberland; brown hæmatite in the Forest of Dean, Cornwall, and Devonshire; and clay ironstone in Wales, Scotland, Yorkshire, Staffordshire, Derbyshire, and Shropshire.

4.—Descriptions of Iron.

Three descriptions of iron are broadly distinguished:—pig or cast iron; malleable or wrought iron; and steel or ingot iron. Of each of these, again, several varieties are recognised.

5.—Cast Iron.

Cast iron consists of iron and very small quantities of carbon, silicon, manganese, sulphur, and phosphorus—the carbon in the whiter varieties being chiefly combined or dissolved, and in the greyer kinds mostly uncombined or graphitic.

For foundry purposes Unwin (in his 'Testing of Materials of Construction') gives the following limits:—

Combined carbon	0·15 to 1·25	2·00 to 4·50
Graphite	1·85 to 3·25	
Silicon		0·15 to 5·00
Sulphur		0·00 to 0·50
Phosphorus		0·00 to 1·30
Manganese		0·00 to 1·50
Iron		90·00 to 95·00
		100·00

When the proportion is not too large, carbon increases the fluidity of molten iron, and makes the pig softer and tougher; in excess it makes iron both softer and weaker, as the proportion of uncombined carbon increases.

Cast iron is inductile, and cannot be forged or welded. It cannot be relied on to stand severe strains suddenly applied, and is untrustworthy under tensile strain.

Within a limited range it is tougher, in compression it is much stronger, and under tension it is much weaker, than wrought iron; it is harder, more brittle, and beyond a small range of stress it is less tough; it is fusible at much lower temperatures; and it is not so readily oxidised.

We may broadly distinguish three descriptions of pig iron—grey, mottled, and white—there being again four gradations of grey pig, of which three are useful for foundry purposes.

More particularly, then, we may say that there are six varieties of pig iron in the market:—

No. 1.—Contains most graphitic carbon, is the most fusible, is soft and tender, has the coarsest texture, with a fracture grey, crystalline, and lustrous, is used for small fine castings, and is generally the dearest.

Nos. 2 *and* 3.—Contain less carbon, are fusible enough for larger castings, where strength rather than fineness of surface is required, and exhibit a lighter grey and less lustrous fracture.

No. 4.—"Bright grey pig" contains least carbon of all the four grey kinds of pig, is not readily fusible, and is used, not for foundry purposes, but for making malleable iron. Its fracture is light grey with very small crystals and but little lustre.

Mottled pig.—So called on account of the appearance of its fracture.

White.—Contains most combined carbon, is the hardest and most brittle, exhibits a white crystalline fracture, and is only used for making inferior bar iron.

The crushing strength and hardness of cast iron are increased by remelting, but, if this be repeated too often, the tensile and transverse strength suffer.

6.—Malleable or Wrought Iron.

Malleable iron contains less carbon than cast iron, but not necessarily less than the milder kinds of steel; it is, therefore, best described as the result of the more or less complete decarburisation and purification of pig iron by the "puddling process." We may say that the purer it is, the more ductile, trustworthy, and valuable it is, as weld iron.

It is malleable (as its distinguishing name implies), ductile, weldable, and tough; it fuses with difficulty and only at a very high temperature; and rusts rapidly when exposed to the influence of a moist atmosphere containing carbonic acid. Its strength under tension and under compression is very nearly equal. The characteristic texture is fibrous, and this will generally be exhibited by fracture. The appearance may, however, be crystalline if the piece be broken by a sudden blow.

"Puddled bar" is the first kind produced in the manufacture. By repetitions of the process of cutting, piling, reheating, and rolling are obtained successively the descriptions of wrought iron known commercially as "merchant bar," "best," "double-best," and "treble-best"; and, as it is thus gradually improved in quality, it is made suitable for rails, ship-plates, boiler-plate, forgings, &c.

7.—Steel or Ingot Iron.

Steel, or more precisely "ingot iron," differs from malleable iron in that it is produced in a state of fusion, and from cast iron in that the ingot formed by the cast metal is malleable.

This statement affords perhaps a better differentiation of ingot iron from both cast and malleable iron than any which involves reference to its composition, or attempts to describe more particularly its special qualities. For the proportion of carbon which it contains in a combined or dissolved state may vary from 0·15 to 1·50 per cent., while in its character it also varies greatly, the milder kinds of steel resembling malleable iron in many respects.

The characteristic fracture of steel is bright and crystalline; but, when ruptured gradually, a mild steel may exhibit a fibrous fracture.

The milder kinds of steel, containing least carbon, resemble wrought iron in toughness, tensile strength, and weldability. The harder kinds are particularly capable of being hardened and tempered by heating and rapid cooling.

Steel is malleable and forgeable, but should be wrought at a lower temperature and treated more carefully than malleable iron. It is more fusible, but steel castings are rough, porous, and generally require to be forged.

8.—Impurities in Iron.

The presence of silicon in pig iron hinders the combination of carbon with iron, and—when it does not exceed 3½ per cent. —tends to produce a soft, grey, strong iron. More than that makes pig iron weak, hard, and brittle. In very much smaller proportions it induces hardness in wrought iron and steel; but as little as 0·35 per cent. renders wrought iron "cold-short" or brittle under the hammer, and 0·5 per cent. makes steel "red-short" or unworkable at a red heat.

Phosphorus tends to make pig iron brittle, but its hardening effect and the increased fluidity which it induces in the molten metal are of advantage in light castings, where strength is not of much importance. More than 0·3 per cent. of phosphorus lowers the tenacity of wrought iron, and makes it "cold-short." Much less renders steel "cold-short," and not more than 0·1 per cent. would be allowed in steel rail specifications.

The presence of manganese in the ore aids the elimination of sulphur, but more than 1 per cent. makes the pig iron white and brittle. In wrought iron its effect is to raise the melting-point. Manganese acts like carbon in increasing the elasticity and tensile strength of steel, but renders it less ductile; and, while it lessens the "red-shortness" due to phosphorus and sulphur, the alloy of manganese and iron makes the steel more liable to rust, and in a purer metal, therefore, its presence is less desirable.

"Cold-shortness" is induced by antimony, tin, and arsenic;

"red-shortness" by copper, calcium, and sulphur; but the worst of these is sulphur.

9.—Preparation of Iron Ores.

The ore, if it contains much pyrites or shale, is broken up and weathered for three or four months, or even for a much longer period. It is then roasted in a kiln in order to expel from it, as much as possible, water, sulphur, and arsenic, and to render the ore porous.

10.—Reduction in the Blast Furnace.

The modern furnace is a huge vertical wrought-iron cylinder lined with brickwork. From the throat to rather below the middle, the stack or body of the chamber gradually bellies out. From here it contracts more rapidly in the boshes down to the hearth. At the bottom of the hearth is a tap-hole, which, while the furnace is working, is plugged with clay; the sides of the hearth are pierced to receive from three to six tuyeres, through which the hot blast is supplied from the main.

Once lit, the fires of the furnace may not be extinguished for years, charges of coke, lime, and ore being added from time to time through the throat.

In its gradual descent the ore is heated, reduced, and decomposed; carbonic oxide, hydrogen, and hydrocarbon gases deoxidise the ore; water and carbonic acid are given off; and the lime, which acts as a flux, combines with the silica of the ore and forms slag.

The reduced iron now takes up a certain amount of carbon and some impurities as well; the metal fuses; the furnace having been tapped, the lighter slag flows off at a higher level; and the impure iron is either run into "pigs," whence it is known as pig iron, or the molten metal is carried at once in travelling ladles to the Bessemer converters to be made into steel.

As the temperature is higher or lower, and the quantity of fuel greater or less, the pig iron produced varies between the greyer and the whiter descriptions.

11.—Castings.

No. 1 is only used for small castings in which fineness, rather than strength, is desired. For larger castings the greater hardness, strength, and toughness required are obtained with No. 2 or 3, or a mixture of these; indeed, mixtures run more solid, and give better results.

The pigs are broken up and melted in a cupola furnace, charges of coke, iron, and limestone being added as required, and a blast supplied by fans or blowers. When the furnace is tapped, the molten metal is caught in a ladle, poured into sand moulds, and allowed to cool gradually. The contraction in cooling is about one per cent. in linear dimension, and allowance must be made in moulding accordingly.

In a specification of cast-iron sleepers, it is not usual to prescribe what kind, or mixture of pig iron, shall be used, but to lay down certain tests. Thus, for Indian State Railway sleepers a cast-iron bar 2 inches deep and 1 inch broad placed on bearings 3 feet apart must bear, without breaking, a weight of 1½ tons and they contract so much in cooling that annealing is necessary. Hardening in oil and then annealing greatly increase their strength and ductility. The moulds are more costly, the melting-point of steel being much higher than that of cast iron; there are more dead-heads, the castings are rougher, they are more liable to contain blow-holes, and they require to be forged. For cast sleepers and chairs, iron is preferred to steel.

12.—The "Puddling Process."

Malleable iron is produced by melting and "puddling" pig iron in a reverberatory furnace, the hearth of which is covered with broken slag, and the whole of the interior lined or "fettled" with a mortar composed of ground red hæmatite or some cheaper substitute.

White pig iron is preferred, and the charge (about 4 or 4½ cwt.) having been introduced, more coal is added, the furnace closed, and the heat raised.

In the "melting down" stage the pigs, as the metal softens, are turned over with a long iron rod; silicon is partly separated, and grey pig is converted into white—graphitic carbon changing to the condition of combined or dissolved carbon.

In the next stage, during which the damper is lowered, and the temperature allowed to fall, the puddler mixes the charge with basic slags which are thrown in.

During the third stage the heat is again raised; carbonic oxide is freely given off in spirts of blue flame, and the metal is said to "boil." As the puddler works the mass vigorously with his rabble, most of the carbon, silicon, phosphorus, and manganese are exposed to oxidation and thus separated.

The "boiling" now subsides; the sinking mass becomes pasty; and granules of infusible iron begin to "come to nature." These, during the "balling stage," are worked into balls by the puddler, and drawn towards the fire-bridge, the cinder falling to the bottom of the hearth.

13.—Manufacture of various Sections of Wrought Iron.

The balls, having been taken out of the furnace, are welded under the shingling hammers, by which the slag is pressed out and the mass consolidated. While still hot, these "blooms" are passed through the "puddling" or "roughing" rolls, and the iron is then known as No. 1, or "puddled bar."

By repetitions of the process of cutting, stacking, reheating, and rolling, the particular qualities of malleable iron required for rails, ship and boiler plates, forgings, &c., are successively obtained.

The proper section of plates, angles, tees, rails, &c., is finally acquired in the "finishing rolls."

For rails the stacks or piles were made up of puddled bars covered above and below with slabs of hard hammered iron, which, after rolling, enclosed the heads of the rails, and thus formed a good wearing surface.

Not only, however, are steel rails far superior to iron rails, but actually cheaper, so that steel has practically superseded iron in this as well as many other manufactures.

14.—Manufacture of Steel.—The Cementation Process.

"Blister steel" is produced by embedding wrought-iron bars in carbon and raising them, while protected from the influence of air, to a long-continued white heat. They thus become impregnated with a certain amount of carbon, but more particularly on the surface.

To obtain greater uniformity these bars are sheared, packed in faggots, raised to welding heat, and hammered or rolled again into bars, which are known as "shear steel"; and "double shear steel" is the result of repeating this treatment.

A more truly homogeneous steel is produced by melting blister steel in crucibles with the addition of manganese or spiegeleisen.

Shear and crucible steel are principally used for making cutting tools. It remains to describe more in detail the Bessemer, Basic, and Siemens-Martin processes, by which steel is now manufactured, possessing almost any desired gradation of qualities, at a comparatively cheap cost and in enormous quantities.

15.—The Bessemer Process.

Bessemer steel is obtained by the partial decarburisation of pig iron—a grey pig iron being preferred, reduced from hæmatite ore and practically free from phosphorus or sulphur. The molten metal is carried in travelling ladles from the blast furnace to the Bessemer converters, or delivered direct from the cupola in which it has been remelted.

These are huge wrought-iron retorts, swung on trunnions, and having a capacity of from 8 to 10 tons. The bottom is removable, and fitted with perforated cylinders of fire-clay, through which the blast is introduced. The interior is lined with ganister, or with fire-brick laid in ganister mortar.

A wood fire is first lit inside the converter, and blasted out when the lining has become red-hot.

The converter is then swung down to receive its charge of molten pig iron, again raised, and the blast turned on. In about twenty minutes the charge is reduced to a state of almost pure iron.

Once more the converter is swung down, in order to receive the charge of molten "spiegeleisen," or ferro-manganese, which flows from a cupola close by, and is required to give the proper admixture of carbon and manganese.

After a few minutes the slag is partially run off, and the molten steel poured into a ladle. In the bottom of the ladle is a hole, whence the fluid metal flows (when the plug is lifted) into the ingot-moulds, most of the slag and other floating impurities being left behind.

The steel having solidified, the moulds are lifted off and the ingots removed to be reheated and passed through the "cogging rolls."

16.—The "Basic" or Dephosphorisation Process.

The acid or silicious slag produced in the Bessemer process has no affinity for phosphorus, so that this impurity cannot be eliminated. Now steel containing as much as 0·2 per cent. of phosphorus with a very low percentage of carbon would be utterly unfit for rails. It was not until Messrs. Gilchrist and Thomas introduced the "basic" process, in which the ganister lining is replaced by one of a strongly basic character, that it was possible to dephosphorise ores which could not be utilised in the Bessemer process.

The basic lining is usually prepared with dolomite, which is either burnt, ground, and applied with tar, or made into bricks and laid with tar.

Before introducing the molten pig iron and slag about 15 or 20 per cent. of burnt lime is thrown in, and with this a basic slag is formed which eliminates the phosphorus.

The blow lasts somewhat longer than in the Bessemer process; and it is during the "after-blow," when a very

A gas rich in hydrocarbons is generated from bituminous coal and other fuel in a separate apparatus and conveyed by mains and culverts to one of the regenerators. Here it absorbs the waste heat, and, passing through, reaches the hearth of the furnace, where it mingles with the air which is necessary for its combustion, and which has been similarly heated during its passage through the other regenerator.

The charge consists generally of grey hæmatite pig, which is first thrown on the hearth, and of four or five times as much wrought iron or steel scrap, old rails, &c. The scrap melts in the more easily fused pig iron, while the oxidising flames play upon the whole mass all the while. After three or four hours samples are taken out and tested from time to time, and, when a satisfactory test-result has been obtained, about 1 per cent. of spiegeleisen is introduced and thoroughly mixed with the molten mass.

The fluid metal is then tapped, caught in a travelling ladle, and cast into moulds.

The marked advantages of this process are economy of fuel and the utilisation of steel scrap.

18.—Steel for Rails and Sleepers.

The varying qualities of steel depend to a great extent upon the proportions of hardening ingredients—carbon, silicon, and manganese.

Considered as constructive materials, the superiority of steel to iron is based upon its higher limit of elasticity, its greater ultimate tensile strength, and its greater ductility. On the other hand, it corrodes more rapidly under adverse atmospheric conditions, and the most rigid care and supervision in its manufacture are required to prevent brittleness and to ensure toughness.

We must look for other qualities, however, in the case of rails; and here the supersession of iron by steel is principally due to the homogeneity and ability to withstand heavy moving loads without being crushed, abraded, or laminated, which distinguish the latter material.

In a paper read before the Institution of Mechanical Engineers, Mr. Sandberg summed up the results of the discussion on steel rails that took place at the International Railway Congress at Paris in 1889.

The general conclusion was that the rails should be as hard as is consistent with safety. Hardness was formerly obtained in slow-running mills with hammered blooms, and the early Bessemer rails wore well. Now, with the direct process and quick-running mills, chemical rather than mechanical means have to be relied on, and this is not in favour of the safety of the rail.

Durability under wear is more important than tensile strength, and the tendency at the Congress was to advocate higher percentages of the two chief hardening constituents, carbon and silicon, than are specified for English rail-steel. Mr. Sandberg, however, advises caution in obtaining hardness by chemical means, which would be attended by greater liability to fracture.

Steel rails are not only thrice as durable as iron rails, but their price is much lower. You can afford, therefore, says Mr. Sandberg, to adopt a heavier section, and then you can harden your metal with much less fear of fracture.

Hitherto, a moderately hard steel has been preferred—containing not less than 0·3, nor more than 0·45 per cent. of carbon; not more than 0·06 of either silicon, or phosphorus and arsenic together, or sulphur; and, besides these, no other ingredient except manganese and iron.

For sleepers, a milder steel, containing less carbon and manganese, is required. The proportion of carbon should not exceed 0·14 per cent.; and sleeper-steel should be able to bear a tensional strain of between 26 and 31 tons per square inch, should give an elongation of not less than 22 per cent. in a length of 10 inches, and show a contraction of not less than 40 per cent. of the original area at the point of fracture.

The following percentage limits and analyses are given of wrought iron, rail-steel, and sleeper-steel; but it must be remembered that test-results prove the suitability of a steel for a particular use much more than a chemical analysis, for there may be marked differences in the composition of steels equally adapted to certain requirements :—

Constituents.	Unwin's Limits.		Actual Analyses.	
	Wrought Iron.	Steel for Rails.	Steel Rails.	Steel Sleepers.
Iron	99·00 to 99·50	98·44	98·47	99·18
Carbon	0·02 to 0·25	0·35 to 0·60	0·35	0·11
Manganese	0·00 to 0·30	0·80 to 1·00	1·01	0·63
Silicon	0·00 to 0·20	0·04 to 0·10	0·05	0·02
Phosphorus	0·00 to 0·15	0·03 to 0·07	0·06	0·06
Sulphur	0·00 to 0·015	0·07 to 0·14	0·06	0·00
	100·00	100·00	100·00	100·00

19.—Manufacture of Steel Rails.

The ingot, having been reheated, is first passed through the "cogging" or "blooming rolls"; the ends are sheared off; and it is divided, if necessary, either by shearing or under the steam hammer, into "blooms." The blooms, heated to redness, are then passed through the "roughing rolls," and lastly through the "finishing rolls."

While still hot, the long rail-piece is carried along live rollers and cut into the proper lengths by a circular saw.

The rails are generally straightened by cambering while hot, not after cooling; the lengths are checked and, if necessary, corrected; and the holes are drilled.

The rails are then stacked for inspection.

20.—Inspection of Steel Rails.

The inspector is assisted by two or more men, who apply the gauge to every rail in each tier in order to check the lengths, and turn the rails over with nippers, so that he may examine them on every side and see whether there are any splits, cracks, cinder, or other defects.

Some must be rejected altogether; but those which are more than one-eighth of an inch too short, or exhibit flaws near the ends, may be marked to be cut.

When all the rails in one tier have been overhauled, the inspector looks along each one and marks those which require to be straightened. He should also apply templates, in order to test the section of the rail and the size and pitch of the fish-bolt holes.

While that tier of rails is being removed, the inspector proceeds to examine the top tier of another stack.

Lastly, the inspector may have a few rails weighed, in order to compare the actual with the specified weight per yard.

21.—Testing Rails.

The composition and qualities of rail-steel are proved by:—chemical analysis; direct tensile test; the dead load test; and the falling weight test.

The chemical composition of wrought iron, rail-steel, and sleeper-steel has been dealt with in Article 18.

At the end of the book are given examples of an inspection report, with details of the dead load and falling weight tests applied to certain of the rails inspected. For the purpose of comparison, moreover, the results of tensile tests applied to pieces of rails and sleepers are shown in another table.

The direct tensile test is applied in a testing machine of either the hydraulic or lever type. A test-piece of a certain diameter, having been turned out of the head of a rail, is subjected to a gradually increasing tensile strain until it is torn asunder. The breaking strain, the difference between the original and fractured areas of section, and the elongation or difference in length between two marks on the bar before and after rupture are then recorded. The tensile strength is thus measured, and the ductility of the sample is indicated by the contraction and elongation. A rail-steel should be able to bear a tensile strain of from 30 to 33 tons per square inch.

The dead load or lever test is also applied in the testing machine. A piece of rail, resting on bearings a certain distance apart, is subjected to a gradually increasing load or pressure, and the temporary deflection is measured from time to time until a permanent set takes place. The deflection indicates the elasticity of the metal until the limit of elasticity is reached, after which the test may be continued until the breaking weight finally determines the transverse strength of the rail, while the deflection which the rail will bear up to rupture shows the ductility of the metal.

The falling weight test consists in letting fall a certain weight from a certain height upon a whole rail or crop-end supported on bearings a certain distance apart. The deflection after each blow is measured and recorded.

Of all these tests the last is considered by Messrs. Sandberg & Snelus to be the most significant and important.

The results of a tensile test applied to a piece cut from the head of a rail, and to a piece turned out of the web or lower flange, would probably show that the tensile strength differs over different parts of the section. Moreover, as Sir Benjamin Baker pointed out, the tensile and dead load tests in themselves are not such as prove the capability of the rail to stand the strain of loads applied not only instantaneously but, so to speak, by shocks and blows; whereas the falling weight attacks the metal suddenly and severely, as it is tried in actual use, and shows at once whether the steel is too soft or too hard.

The following are the main points laid down in a specification for Indian State Railways Bessemer steel rails, double-headed, 73 lbs. per yard:—

To be made from a mixture of hæmatite pig iron and charcoal spiegeleisen.

To be of uniform section throughout, true to template, perfectly sound and straight, free from splits, cracks, scoriæ, and defects of every kind, their weight being as nearly as possible

73 lbs. per yard. Any rails bent or warped in the manufacture to be straightened by pressure, and not by hammering. The ends to be cut true and square, and burrs caused by the saw to be carefully removed.

The length to be 30 feet,* but a very small percentage of 27-foot, and 24-foot rails may be accepted; these shorter lengths being cut, while cold, from longer rails defective near the ends, no reheating being allowed. The rails to be within $\frac{1}{8}$ inch of the specified length.

The bolt-holes to be drilled clean and square to the web, without burrs on either side, and to correspond exactly with the gauges supplied. The holes not to be punched before being drilled.

Subjected to analysis, the rails must not contain of:—

Carbon	more than 0·45 per cent. or less than 0·3 per cent.	
Silicon	”	0·6 per cent. each,
Phosphorus	”	
Sulphur	”	

and there must be no other material present, except manganese and iron. In some specifications arsenic is mentioned, and it is laid down that the rail-steel must not contain more than 0·6 per cent. of arsenic and phosphorus together.

The following tests to be applied:—

(1) A weight of 28 tons being suspended for half an hour from the centre of a 30-foot rail on wrought-iron bearings, equidistant from its ends and 3 feet 6 inches apart in the clear, the deflection not to exceed $\frac{3}{8}$ inch, and no permanent set to appear on the removal of the load.

(2) The rail, being supported as above, to bear without the least sign of fracture two blows from a cast-iron monkey, weighing 1 ton, allowed to fall freely from a height of 20 feet upon the centre of the rail. The permanent set caused by the first blow to be between $1\frac{3}{4}$ and $2\frac{1}{2}$ inches; the total deflection, after the second blow, not to exceed 5 inches.

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* Forty-foot rails have already been introduced on the Bengal and North-Western Railway.

(3) Whole rails, broken by a weight of 1 ton falling from the necessary height, to show a perfectly sound and homogeneous fracture.

22.—Forms of Rails.

There are three forms of rails in common use—the "Vignoles" or flat-footed, the double-headed, and the bull-headed.

These are all modifications of the **I** section, a form suggested by the work which a rail has to do, considered simply as a girder.

The edges of the upper table must, however, be rounded to suit the wheel-tires; allowance must be made for wearing down; and the mass of the head is distributed rather in depth than in width. In the lower flange of "Vignoles" rails the width and flatness of the girder section are retained.

But, if the rail is to be reversible, the foot of the rail must be the same as the head, and we thus obtain the double-headed rail, which does not rest directly upon wood sleepers, but requires the intermediate support of cast-iron chairs.

The lower table of the double-headed rail, however, resting on the chair, is apt to become so dented that it is scarcely serviceable when reversed. A lighter flange, therefore, is adopted for the foot of the rail, and thus the bull-headed section is developed. The bull-headed rail in heavy cast-iron chairs (Figs. 5, 6, and 7)—the type of permanent way generally adopted on British railways—is admirably adapted to withstand the shocks and vibrations of quick and heavy traffic.

The angle between the fishing-planes should be as small as possible; in other words, the under-slopes of the upper, and the top-slopes of the lower, flange should be as flat as practicable for easy rolling in the mills, in order that the support of the fish-plates at joints may be as direct, and the strain thrown on the bolts as little, as possible.

English rails (Figs. 2, 3, 4, 5 and 6) generally have too wide an angle, as much as 50° or 60°, the Highland Railway rail being singular in having so flat an angle as 40°. The modern tendency, however, is to flatten the fishing-angle much more than that. The fishing-angle of Mr. Sandberg's Goliath rail of 1889 is 30°, that of the Indian State Railway 75-lb. rail (Fig. 8) about 28°, while that recommended by the American "Committee on Standard Rail-sections" is not more than 26°.

At the same time the head is made wider and less in depth than in older types, the sides of the head are straight, and the top is flatter. The interior of the head wears so much more rapidly than the surface metal, that a flatter and wider head is much more economical than a deep one; it affords the engine a better grip; and there is less grinding flange wear than with rounder edges and spreading sides.

The following dimensions of recent types—the Indian State Railways and that suggested by the American Committee—of 75-lb. flat-footed rail-sections may be compared:—

	Head.					Web.				Flange.					
	Width.	Central depth.	Radius of top corner.	Radius of lower corner.	Angle of under-side.	Thickness.	Depth.	Radius of fillets.	Radius of sides.	Width.	Central depth.	Radius of top corner.	Radius of lower corner.	Angle of top slope.	Total depth of rail.
	in.	in.	in.	in.		in.	in.	in.	in.	in.	in.	in.	in.		in.
American ..	$2\frac{15}{32}$	$1\frac{27}{64}$	$\frac{5}{16}$	$\frac{1}{16}$	13°	$\frac{17}{32}$	$2\frac{35}{64}$	$\frac{1}{4}$	12	$4\frac{13}{16}$	$\frac{27}{32}$	$\frac{1}{16}$	$\frac{1}{16}$	13°	$4\frac{13}{16}$
Indian State	$2\frac{3}{8}$	$1\frac{5}{8}$	$\frac{3}{8}$	$\frac{1}{8}$	14°*	$\frac{9}{16}$	$2\frac{1}{2}$	$\frac{1}{4}$	∞†	4	$\frac{7}{8}$	$\frac{1}{4}$	$\frac{1}{16}$	14°*	5

* 1 in 4. † Flat.

In the older forms the deep head and flat thin foot received such different amounts of work in the rolls, and cooled down after rolling at such different rates, that the interior of the head was apt to prove spongy, and the greatest care was required in straightening the rail.

The new designs conduce to more even cooling, with less risk of internal strain, so that the rail may be, as nearly as possible, straight in all directions. With this object, the amount of metal in head and foot is balanced as evenly as economy will permit; and—while the proportions of weight in head, web, and flange of Mr. Sandberg's "Goliath rail" of 1889 were 45·5, 22, and 32·5 per cent. respectively—the American Committee recommend 42, 21, and 37 per cent. (see 'Transactions of the American Society of Civil Engineers,' June, 1893).

For similar reasons, the web of a rail is made thicker than mere strength requires. The webs of English rails are exceptionally thick, especially of those which run through chemical districts, where rusting is comparatively rapid.

Railways.	Gauge.		Section.	Weight per yard.	Depth.	Width of head.	Thickness of Web.	Angle between fishing-planes.
	ft.	in.		lbs.	in.	in.	in.	°
London and North-Western ..	4	$8\frac{1}{2}$	B.H.	90	$5\frac{9}{16}$	$2\frac{3}{4}$	$\frac{13}{16}$	50
North-Eastern	,,		,,	90	$5\frac{5}{8}$	$2\frac{9}{16}$	$\frac{11}{16}$	58
London and South-Western ..	,,		,,	87	$5\frac{9}{16}$	$2\frac{1}{2}$	$\frac{11}{16}$	50
Great Western	,,		,,	86	$5\frac{9}{16}$	$2\frac{3}{4}$	$\frac{11}{16}$	45
Lancashire and Yorkshire ..	,,		,,	86	$5\frac{9}{16}$	$2\frac{5}{8}$	$\frac{3}{4}$	45
Manchester, Sheffield and Lincoln	,,		,,	86	$5\frac{5}{8}$	$2\frac{3}{4}$	$\frac{13}{16}$	50
Metropolitan	,,		,,	86	$5\frac{9}{16}$	$2\frac{1}{2}$	$\frac{11}{16}$	48
Midland	,,		,,	85	$5\frac{5}{8}$	$2\frac{5}{8}$	$\frac{3}{4}$	60
Great Eastern	,,		,,	85	$5\frac{1}{2}$	$2\frac{5}{8}$	$\frac{11}{16}$	65
London, Brighton and South Coast	,,		,,	84	$5\frac{3}{8}$	$2\frac{11}{16}$	$\frac{3}{4}$	52
North British	,,		,,	84	$5\frac{3}{8}$	$2\frac{1}{2}$	$\frac{11}{16}$	60
London, Chatham and Dover ..	,,		,,	83	$5\frac{5}{16}$	$2\frac{9}{16}$	$\frac{11}{16}$	50
Hull and Barnsley	,,		,,	80	$5\frac{1}{2}$	$2\frac{1}{2}$	$\frac{3}{4}$	70
Highland	,,		,,	80	$5\frac{1}{4}$	$2\frac{1}{2}$	$\frac{11}{16}$	40
Indian State	3	$3\frac{3}{8}$	F.F.	50	4	2	$\frac{2}{5}$	30
,, ...	5	6	,,	75	5	$2\frac{3}{8}$	$\frac{9}{16}$	28*
East Indian (old)	,,		D.H.	75	$5\frac{3}{16}$	$2\frac{3}{8}$	$\frac{3}{4}$	64
,, (new)	,,		B.H.	85	$5\frac{11}{20}$	$2\frac{7}{10}$	$\frac{16}{25}$	28*
Great Indian Peninsula (light)	,,		D.H.	69	5	$2\frac{3}{8}$	$\frac{21}{32}$	58
,, ,, (heavy)	,,		B.H.	82	$5\frac{1}{2}$	$2\frac{3}{8}$	$\frac{21}{32}$	58

* Slope of 1 in 4.

Finally, having regard not merely to steady wear and tear but to the shocks and jars which a rail must suffer under fast and heavy engines oscillating and pounding over it, a far heavier section is demanded than would be necessary on our first consideration of a rail as a simple girder. With slow speeds the distribution of the weight on the axles may be a measure of what the road has to bear, but at high speeds the whole weight of the engine attacks the rail almost instantaneously. When exposed to the vibration of heavy and fast traffic, a light permanent way is shaken to pieces, and a heavy rail on sleepers spaced sufficiently close to each other is true economy.

The details of some British and Indian rails, given on the preceding page, will no doubt be interesting.

23.—Fish-plates and Fish-bolts.

The suspended joint, with fish-plates instead of joint-chairs, was introduced by Mr. Bridges Adam as long ago as 1847.

Steel for fish-plates is commonly specified to be made from a mixture of best English or Spanish hæmatite pig-iron and charcoal spiegeleisen, and to be equal to a tensional strain of not less than 28 nor more than 32 tons per square inch, with

Thus, while the Great Western uses the plain pattern shown in Fig. 4, many other English railways adopt the clip pattern illustrated in Figs. 2 and 3. The new Indian State Railway standard fish-plate (Fig. 8) assumes a more or less girder-like section, while the old one had an angle section. Sandberg's fish-plate is also of angle section, but it rests on the sleeper flush with the foot of the rail, and has holes through which dog-spike fastenings are driven into the sleeper. On the Great Indian Peninsula Railway the web of the end of the rail is sufficiently cut away to admit of a central fish-bolt being passed through, and thus holding up the fish-plates at the very point where the joint most requires support.

In length the Indian standard fish-plates run to 21½ and 22 inches, but the English patterns do not exceed 18 to 20 inches. With chair-keys that can be driven from either side, the sleepers next to the joint may be placed as near to each other as will allow of easy packing, and closer guard sleepers and shorter fish-plates are to be preferred.

Unless the neck of the fish-bolt is square (as on the Midland) or pear-shaped or one-quarter square (as on the Great Western), fitting holes of the same shape in the corresponding fish-plate, the latter must be grooved or channelled (as on the London and North-Western, Fig. 3), to grip the square head of the fish-bolt, and prevent it from turning when the nut is being screwed up. Otherwise the head of the bolt may be cup-shaped (as on the Midland and Great Western Railways, Figs. 2 and 4).

The nut of the fish-bolt may be plain or (as on the Midland) lock, square (as on the Great Western) or hexagonal (as on the London and North-Western Railway). The Indian State Railway standard fish-bolt (Fig. 8) had a washer under the nut, but a later pattern has the angles of the nut cut away for a depth of ⅛ inch, and the washer is dispensed with. If the nut is well chamfered on the face next to the fish-plate, no washer is necessary. Spiral and spring washers are sometimes used, but such expedients for keeping the bolt tight should not be required.

As a rule the nuts are placed outside the rail, but occasionally (as on the London, Brighton, and South Coast Railway) we find them on the inside, even when the keys of the chairs are driven outside.

The bolts pass through round or oval holes in the rail, $\frac{1}{4}$ to $\frac{3}{16}$-inch play being allowed for expansion or contraction of the rails. Thus, the longer diameter of the Midland and Great Eastern oval bolt-holes is $1\frac{1}{8}$ inch, to take a $\frac{7}{8}$-inch bolt; while the Indian State Railway rails are drilled with $1\frac{3}{16}$-inch round holes for a bolt 1 inch in diameter.

A few dimensions are here given for the purpose of comparison:—

Railways.	Rail.	Fish-plates.			Fish-bolts.	
	Weight per yard.	Weight of a pair.	Extreme depth.	Length.	Number.	Diameter.
	lbs.	lbs.	in.	in.		in.
London and North-Western ..	90	$54\frac{1}{2}$	$5\frac{1}{4}$	20	4	$\frac{7}{8}$

25.—Form and Manufacture of Steel Sleepers.

Steel sleepers have generally the section of an inverted U, and the flange of the Vignoles rail is either held by clips rivetted or bolted to the sleeper—as in most Continental types —or is keyed up between clips punched up from the mass of the sleeper itself, as in the Indian State Railway pattern.

Until lately, the latter consisted of three pieces only, the trough and two keys, both the latter being driven outside on the straight, and one or both inside—to widen the gauge as required —on the curve. But the space between the clips was too narrow to allow one sleeper to be replaced in the road without disturbing the others or bending back the clips, which, although most objectionable, was sometimes done by platelayers.

In the standard pattern of 1893, therefore (Fig. 9), the clips are not only stiffened or corrugated, so that they cannot thus be tampered with, but the clearance between them is $\frac{3}{8}$ inch wider than the flange of the rail, so that the rail can be dropped in, or the sleeper taken out of the road with ease. The only objection to the new pattern is that it necessarily consists of five parts, there being two distance-pieces placed outside the rail, as well as two keys driven inside, except on curves, where the position of one or both keys and distance-pieces is reversed, according to the extra width of gauge required.

The sleeper-plate is 9 feet long and 1 foot $1\frac{1}{2}$ inch wide; its thickness varies from $\frac{3}{8}$ inch, over a width of about 5 inches along the middle, to $\frac{5}{16}$ inch at the sides; and the ends as well as the sides are turned down to hold the packing, the length of the shaped sleeper being 8 feet 9 inches. The width of the rail-seat is 4 inches, giving a bearing surface of 16 square inches. The weight of the sleeper, with fastenings, is 139 lbs. :—

	lbs.
Sleeper-plate	135
2 distance-pieces	2
2 keys	2
	139

In the manufacture the plates are reheated and shaped, while red hot, in a powerful press, which at the same time gives a tilt of 1 in 20 to the rail-seat and punches up the clips. It is important to stamp all the plates at as nearly as possible the same heat, so that there may be no sensible difference of gauge. Instead of being rolled in flat plates the steel may, otherwise, be at once worked to channel section in the mills, and then pressed to shape under the die. The finished sleepers are dipped either in a bath of tar when cold, or at a high temperature in a boiling solution of coal tar and tar oil.

The steel sleeper has also been designed, but less successfully, to take double or bull-headed rails. Thus, in Webb's sleeper, of which 100,000 were laid on the London and North-Western Railway, the rail is supported by three pieces rivetted on to the trough—a seat on which it rests, and two side-pieces between which it is wedged up by a steel spring key. In Riley's pattern, some of which were laid on the North-Eastern Railway, clips are pressed up out of the mass of the sleeper, made thicker at that place in order to offer sufficient stuff. In the Howard type, tried on the Great Northern Railway, two tongues or lugs are cut out and pressed down, affording an elastic seat for the rail, which is secured by a wooden key. Steel sleepers have, however, found so little favour in England, that no further description is necessary of the various patterns which have been experimentally laid.

26.—Testing Steel Sleepers.

The sleepers having been laid out on benches, the inspector selects a few, has rails fitted on them and keyed up, and tests the gauge. He has a certain number flattened out under the steam hammer, when flaws in the shoulders may be detected; and the clips are tested by being doubled back. Should there be more than 0·14 per cent. of carbon in the steel, the clips will fail under this test. Sleeper-steel should show no sign of crack or fracture on being doubled back till the inner radius of the bend is equal only to half the mean thickness. Samples are also cut out of selected sleepers and subjected to tensile strain in the testing machine; examples of this test are given at the end of the book. The conditions to be filled under tensional strain are specified in article 18.

There must be no burrs on the clips, or the keys will not drive fairly, and the plates must be free from furrows or corrugations. Much greater pains are now taken than formerly to make the clip and key or distance-piece fit each other closely.

27.—Cast-iron Sleepers.

Of cast-iron sleepers, two types may be considered, the bowl or pot and the plate, with wrought iron tie-bars and fastenings.

The Great Indian Peninsula Railway's standard pattern (Fig. 11) offers an example of the former. It is known as the "R and L" (or right and left) pot, and consists of:

				lbs.
2	cast-iron pots	weighing	.. ..	202·00
1	wrought-iron tie-bar	„	.. ..	25·75
2	„ cotters	„	.. ..	1·00
2	„ gibs	„	.. ..	0·41
				229·16

The bowl or pot is oval, with two seats for the rail, jaws such as a chair might have to hold rail and wooden key, two holes for packing, and bearings to take the tie-bar and fastenings. The pots are right and left, so that the tapering keys may be driven in the same direction on both rails. Wooden rest-pieces are not, in this pattern, inserted between rail and bearing, as in the older designs. It was found that rest-pieces of elm, oak, &c., creosoted or otherwise prepared, so corroded the double-headed rail that it could not be inverted. Other patterns, still in use but not imported, are known as the "round" (these were their earliest), the "old oval," and the "new oval"; but these are all inferior to the "R and L" pots.

The experience of the Great Indian Peninsula Railway is valuable, for they have laid most of their road with cast-iron pots, their sleepers being thus distributed at the end of 1893 :—

Teak wood	487,859
Pine wood	101,609
Other woods	39,810
360 miles of wooden sleepers	629,278
Round pots (pairs)	454,162
Oval, old pattern (pairs)	934,637
„ new „ „	557,087
„ R and L „	899,800
1632 miles of cast-iron sleepers	2,845,686

Their chief engineer says that the "R and L" pot makes an excellent road, and breakages are very small.

The average renewals per annum of cast-iron pot sleepers, between 1873 and 1892, have been 0·80 per cent. only, as against 4·57 per cent. for wooden ones. During 1893 the wood renewals were as much as 6·14 per cent., the cast iron renewals being only 0·57 per cent. "The increase in wood renewals," the chief engineer explains, "is due to the rejection of sleepers before their life had ended, rather than lay new rails on them. Our renewals are carried on in continuous lengths, and we make the road as thoroughly good as it can be made to avoid any early call for disturbing it, in other words, the increase may be put down as the result of our improving policy. The decrease in iron sleeper renewals is due to the gradual increase of the stronger (standard) type, and to the use of better ballast. In the old days dirty ballast, which caked in the pots, caused great destruction of the weaker oval pots. About 75 per cent. of our ballast is either trap-stone broken to cubes with about 1 inch sides, or screened river shingle; the rest is of sand or other inferior material, which we are rapidly discarding."

Of the cast-iron plate sleeper we have an example in the Denham-Olpherts or "D. O. sleeper," which consists of two cast-iron plates, with wrought-iron tie-bar, cotters, and keys

(Fig. 10). The inner jaw is a separate piece applied to the rail and keyed to the plate, and the rail is suspended in the jaws, there being no wooden key as in other cast-iron sleepers. The earlier type had a light jaw with a wooden packing-piece to carry the rail, instead of a heavy jaw in which the rail is suspended.

The East Indian Railway have adopted the "D. O. sleeper" as their standard, and there are 2,483,609 of them laid in the road. The annual breakages during the last five years averaged 0·64 per cent.

"It is," says the chief engineer, "easily handled and put together. With ordinary care in packing, it makes a good even road; and I think the running on the East Indian Railway compares favourably with other large lines in India, where different types of permanent way are in use. The D. O. plates have to be carefully packed, as the gauge can be altered ½ inch by packing more on one side than the other."

Our experience of these sleepers on the Eastern Bengal State Railway is equally favourable, but it must be remembered that they were in both cases laid on a well consolidated road-bed. On a new line, the Delhi-Umballa-Kalka Railway, the breakages were as much as 4 per cent. during the first year, and would not sink to the East Indian Railway and Eastern Bengal State Railway averages until the banks were thoroughly settled.

The D. O. sleeper is exposed to a severer test when laid on the sharp curves and heavy gradients of the Frontier section of the North-Western Railway. Nevertheless, the engineer-in-chief reports that it makes an excellent road to maintain and run on, and the breakages are small. On sharp curves, however, it is found that the tie-bars are scarcely strong enough; where the cant on curves is considerable, they bend and tighten the gauge; the inner jaw, moreover, cuts into the flange of the wheel. If care be not taken in packing, the plate tilts, the gauge tightens or widens, and, as the tie-bar is liable to bend, the gauge may ultimately be thrown out still more. On points and crossings, the heel and slide chairs used with this description of permanent way are, say the Frontier engineers, cumbersome, and the bridge chairs are not satisfactory, the cotter working loose.

The falling weight test applied to these sleepers is that of a tup weighing 3½ cwt. falling through a height of 2, 3, 4, 5, 6, 7, 8, and 9 feet successively, on the head of a piece of rail 18 inches long, keyed up in a plate bedded on sand—the average fall at which breakage occurs not to be less than 7 feet, or the day's make to be rejected; one plate out of every 200 to be thus tested.

28.—Wooden Sleepers.

Hard wood is preferred. Sleepers should consist of thoroughly sound and seasoned wood, as free as possible from sapwood, large or loose knots, shakes, cracks, or defects of any kind.

In England the sleepers generally consist of Baltic fir, adzed by machinery on the sap side sufficiently to seat the chair fairly, bored right through, creosoted after being adzed and bored, and laid with the heart-side downward. They measure 9 feet by 10 inches by 5 inches, and weigh about 134 lbs. The chairs are fixed on before the sleepers are sent out. Pitch pine, Scotch fir, and larch are also in use on British railways.

In India, deodar, sâl, and teak are the most common sleeper-woods; the two latter are preferred to deodar for bridge and crossing sleepers. Pyingado and asun are also in use. White ants will attack neither pyingado nor teak. Within a certain distance from the port of landing, creosoted pine, imported from Europe, is often cheaper than indigenous woods. The broad (5 feet 6 inches) gauge wooden sleeper (Fig. 8) on Indian State Railways generally measures from 9½ to 10 feet by 10 inches by 5 inches, and the metre gauge sleeper 6 feet by 8 inches by 4½ or 5 inches.

There are several processes by which railway sleepers may be more or less preserved. The efficiency of the "kyanising process" is doubtful, as the corrosive sublimate is liable to be washed out by excessive moisture. "Burnett's process" is open to the same objection when the chloride of zinc solution is weak enough not to affect the strength of the wood. In France "Boucherie's (sulphate of copper) process" has been largely used; while in England sleeper-wood is generally creosoted. After being adzed and bored, the sleepers are packed in an hermetically closed cylinder, the air is pumped out, creosote is allowed to flow in, and is finally forced in by the pumps until the wood-fibre is saturated with it. Ordinary sleepers of deodar and other indigenous woods last fairly well in India, if the climate be a dry one, without any protection at all; but it is usual to cover bridge-sleepers of teak or sâl with a coat of tar.

The sleepers are generally arranged transversely. In section they may either be half-round or rectangular, the latter as a rule. If the rail be bull- or double-headed, the inward tilt of the rail is given by the peculiar form of the chair, and that portion of the sleeper on which the chair rests is merely truly planed; but where the flat-footed rail rests directly upon it, the sleeper is adzed to an inward slope of 1 in 20, so that the rail has a corresponding cant of 1 in 20 from the vertical inwards.

If the sleepers are arranged longitudinally, as is seldom the practice now, they are connected by transoms and bolts at intervals.

29.—Chairs.

Cast-iron bowl or pot sleepers are so designed as to form a combined sleeper and chair for double-headed or bull-headed rails, but with wood sleepers the intermediate support of a cast-iron chair is required. The rail generally rests on a seat, and fits tightly against one jaw when the key, which is usually of pressed oak, is driven between the rail and the other jaw.

It is found that the lower tables of double-headed rails are often so chair-marked that it is useless to reverse them; and accordingly in one form of chair the head is suspended in the jaws, the lower table of the rail not touching the chair. In this case, however, the blow of a passing train is not transmitted to the rigid chair through the more elastic medium of the whole section, but only through the head, and this loss of cushion is a disadvantage affecting both the rail and chair. A better remedy is a broader chair-seat.

On the Midland Railway the cast-iron chair (Fig. 7), carrying an 85-lb. steel rail, weighs 50 lbs., has a base of about 108 square inches (15½ inches by 7½ inches over all) on the sleeper, and offers the rail a bearing 7½ inches long.

The London and North-Western chair (Fig. 5) carries a 90-lb. rail, weighs 45 lbs., has a net base-area of about 107 square inches (14⅜ inches by 7¾ inches over all), and gives a rail-seat 7½ inches long.

The Great Western chair (Fig. 6), with an 86-lb. rail, weighs 46 lbs., rests on the sleeper with a base-area of about 107 square inches (15⅛ inches by 7½ inches over all), and affords the rail a bearing 6⅞ inches long.

The London, Brighton and South Coast chair, supporting an 84-lb. rail, weighs 44 lbs., and has a net base-area of 112 square inches.

There is, in the case of the London and North-Western, a hair felt packing, ⅛th of an inch thick under the weight of the chair before the fastenings are put in, between the chair (Fig. 5) and the sleeper.

The chairs of the Great Western and London and North-Western are designed to give the rail a tilt of 1 in 20, as on Indian State Railways; in the Midland chair the rail has an inclination of 1 in 22 to the vertical.

The old East Indian Railway chair only weighed 30 lbs. According to the last English Board of Trade Regulations, a rail should weigh at least 30 lbs. on light, and 40 lbs. on heavy, roads. It will be noticed that the English chairs are well over the minimum weight for heavy roads.

In India chairs are often made with tapering jaws and keys, so that the latter (of babool or other hard wood) can only be driven from one side. The inconvenience of this at joints is obvious, and the tendency to encourage the travel of rails in opposite directions will be noticed elsewhere.

The English chairs, referred to above, have no taper; nor have the keys, which are of oak and 6 or 7 inches long; the edges of the key-seat on the jaw are rounded off, and there is either a depression in the jaw, or (as in the London and North-Western chair in Fig. 5) there are several of such depressions separated by horizontal ridges, so that the key, as it swells, may fill the spaces and hold tightly.

Thus wedged up, the rail and chair are as one mass and, with a base 14 or 15 inches wide, the lateral stability is immensely superior to that of a flat-footed rail, spiked directly to the sleeper and having a base of, perhaps, 4 inches or less in width.

The key is usually driven outside, but sometimes inside, the rail. The gauge is ensured with an inside key, but the key is more liable to be slackened by a passing train. The outside key affords a better cushion; the argument that, if an inside key falls out, the rail is still kept in place by adjoining inside keys, is not of much practical importance; and the outside position is generally preferred. It is convenient for the keyman to have to examine and tighten both keys and fish-bolts on the same side, whichever it may be.

The following are the main points laid down in a specification for cast-iron chairs for Indian State Railways 73-lb. double-headed steel rails:—

The cast iron to be a mixture of soft grey, all mine iron, and of such a quality that (1) in the transverse test a bar 1 inch broad and 2 inches deep, on bearings 3 feet apart, shall bear a load of 30 cwt. in the centre without breaking, and show a deflection of at least 0·29 inches; and (2) that a bar 1 inch square for a length of 1½ inches in the middle, shall exhibit a tensile strength of 11 tons per square inch of sectional area.

The castings to be sharp and clean, and free from all blowholes, honeycombings, sponginess, broken surface, &c.

Great attention to be paid to the position, size and form of the jaws in which the rail rests, and to the tilt (1 in 20) of the rail when keyed up.

The chairs generally to be thoroughly dressed when cold, and made quite free from lumps, box parting ridges and other roughness.

No hand-moulding allowed: all chairs to be moulded by machine. After being cast, the chairs to be protected, so that they may cool slowly and evenly.

30.—Fastenings.

The flat-bottomed rail is fastened down to the sleeper by dog-spikes (Fig. 8), wood-screws, or fang-bolts with clips. Sometimes—especially at joint-sleepers and on curves—the rail rests on a bearing-plate, through holes in which the dog (Fig. 8) or screw is passed. In the Board of Trade requirements it is laid down that, with F. F. rails, the fastenings at joints and at some intermediate places must be fang or other through-bolts.

In hot and dry climates, however, fang-bolts are liable to work loose. The wood swells in the rainy season, the bolts then rust in, and when the wood shrinks again in the dry season the fang loses its hold, so that, in screwing up, the bolt is merely turned round uselessly in the hole. Wood-screws are better, chair (Fig. 6) is secured by two fang-bolts only, and these are said to be most satisfactory fastenings. On the London, Brighton and South Coast and the London and South-Western railways the chair is held by three spikes in hollow trenails, two outside and one inside the rail, and in the former case the spike has a notched end.

31.—Double-headed, Bull-headed, and Flat-footed Rails compared.

In India, and on the continent of Europe, where the speed and lateral strain are not so great as in England, the flat-footed rail held down by dog-spikes, especially on base or bearing-plates, is generally equal to all requirements. (The bearing-plate illustrated in Fig. 8 is not the most recent pattern adopted on Indian State Railways. In the new design there is no inside ridge at the inner edge of the foot of the rail, the outer ridge is more prominent, and the inner spike-holes are closer together—2½ inches only, centre to centre.) Otherwise, held by clips and keys in such a steel sleeper as that in use on Indian State Railways, the flat-footed rail is as securely fastened as one can desire.

The strong lateral support afforded by chairs leads at once, however, to the adoption of either double-headed or bull-headed rails, wherever the permanent way has to carry heavy loads moving at great speed.

The economy of a double-headed rail, with four edges to wear out, would seem to be obvious, but the lower side frequently becomes so dented by the chair, that the rail, when inverted, is, perhaps, only fit for sidings. To avoid this, the double-headed rail is sometimes suspended in the jaws of the chairs, as in the jaws of the D. O. sleeper in Fig. 10. Although, in this case, the shock of heavy trains must be more or less concentrated on the head, instead of being distributed through the whole mass of the rail, the suspension of the rail does not appear to be detrimental on the East Indian Railway. Otherwise, when the rail rests on the chair, the only effectual prevention of chair-marking is good keying, firm packing, and a clean chair-seat. In England, where double-headed rails are but rarely used, it has been found of advantage to invert them every two years.

Another objection to the inversion (and, therefore, to the adoption) of double-headed rails is that, after being subjected for years to tensional strain as the lower flange, that portion of the rail must necessarily be less able to bear compressive strain as an upper flange, and turned rails accordingly fail rapidly. The upper flange, moreover, having got hardened and lost much of its elasticity, either cracks when inverted, or throws excessive stress on the other flange, now become the head.

On English railways, therefore, the bull-headed rail is in almost universal use. A heavy bull-headed rail in massive chairs is best able to bear the shock and vibration of the rapid and enormous traffic of the great main lines.

32.—Longitudinal and Transverse Wooden Sleepers compared.

The old Great Western bridge-rail, carried on longitudinal timbers, with transoms and bolts to keep the gauge, made a splendid way, but it has disappeared with the 7-foot road. The continuous bearing permitted the use of a comparatively light rail—62 lbs. per yard—and the joint was excellent.

On a broad gauge the longitudinal system might actually demand less timber than the transverse, but, generally, the first cost must be much greater on account of the larger scantling required; repairs are less easily made; the sleeper-frame has a tendency to open outwards like a book; and the rail lies with the grain, so that it must either cut into the timber, or thin packing-pieces of wood—with the grain at right angles to the line of way—must be inserted, which is troublesome.

The transverse arrangement is at once more convenient, more economical, and—we may practically say now—is universally adopted.

On abutments of bridges a longitudinal sleeper-frame may often be introduced with great advantage, in order to carry trains easily and smoothly on to the girders.

33.—Metal and Wooden Sleepers compared.

Wrought iron—as a material for sleepers—may at once be discarded in favour of steel.

Mr. H. K. Bamber (in Minutes of Proceedings of the Institution of Civil Engineers, Vol. CIX., 1891–92) claims for steel sleepers of the "inseparable clip" type, in use on Indian and Colonial railways, the following advantages:—

"1. They are easily handled and laid in the track. 2. They hold well in line and surface. 3. The gauge can be readily adjusted on curves, by keying up one or both of the rails inside. 4. The clips are not too rigid, and the keys keep well in place when once properly driven up. 5. The maintenance is easy when the track has once become consolidated. 6. If damaged by derailment, the sleeper can be repaired and made serviceable at small cost. 7. Except where ballast has been impregnated with saltpetre, &c., the sleepers have not been found to rust much."

They are easily laid, as described in Article 37. The 1893 pattern for Indian State Railways is still more easily laid and changed; it is susceptible of finer differences of adjustment on curves; but it aims at greater (not less) rigidity in the clips, for they are corrugated. Steel sleepers hold well in line and surface, now that greater care is taken to ensure a much more perfect fit between jaw and rail. They are difficult to pack on soft embankments, such as "cotton soil," especially in the rains; but, after a year or two, on a consolidated bank free from brackish soil, and with ample and clean gravel ballast, there should be a sensible saving in maintenance. In India we can do nothing with a deformed steel sleeper; and, from facing-points to facing-points of single-line stations in India, flat-footed rails should be laid on wooden—not on steel—sleepers. Most derailments occur at points and crossings, and it is very troublesome to replace a deformed steel sleeper, while a wooden one can easily be slipped in.

Steel sleepers do not readily lend themselves to use with double- or bull-headed rails.

Unfortunately, in India, they have been too frequently laid on brackish soil and moist. Thus, on that portion of the North-Western Railway which runs westward between the Salt Range of hills and the right bank of the Jhelum river, and is exposed for months to inundation, and saturated with drainage from the hills, marked sleepers, which weighed 1 cwt. 1 qr. 8 lbs. in 1886, were found to weigh on the average only 3 qrs. 3 lbs. in 1890—a loss of 2 qrs. 5 lbs. in four years. And, if rust once begins, a steel sleeper will fail rapidly, for it has much less metal to wear through than a cast-iron pot or plate.

In the Great Indian Peninsula Railway's standard pattern (Fig. 11) we have a good example of the cast-iron pot or bowl, and the "D. O. sleeper"—adopted as their standard by the East Indian Railway, and largely used by other railways in India—is the best type of the cast-iron plate within our experience. The wrought-iron ties, gibs and cotters rust more rapidly than the cast-iron pots or plates, and are taken out and renewed with difficulty.

In no country, probably, is a freer trial given to wood and metal as material for sleepers than in India; and, in deciding more care, although it may be less liable to break, in packing. With a D. O. plate sleeper a double-headed rail may be used without injury to the lower flange, because the rail is suspended; but the direct suspension of the head of the rail in cast-iron jaws, without the elastic cushion of a wooden key, and without the further elastic foundation of a wooden sleeper, would scarcely be considered suited to the conditions of English traffic.

The heavier sleeper has the advantage of greater inertia, but its weight is to some extent a drawback when the matter of long carriage has to be considered. On the 5′ 6″ gauge, a sâl-wood sleeper, with chairs and spikes, may weigh 280 lbs.; a deodar sleeper with bearing plates and dog-spikes, not more than 155 lbs.; the Great Indian Peninsula pot sleeper, 229 lbs.; the "D. O. sleeper," 230 lbs.; and the Indian State Railways steel sleeper, 139 lbs. only.

The cost of carriage will depend on the weight of the sleeper, the distance it is carried, and the means of transport.

The price, even of the same sleeper and in the same place, may vary considerably—according as an Indian railway, for example, casts its own plates or bowls, or imports them from England. Moreover, we must have regard to the first cost not merely of the sleepers, but of all necessary parts and fastenings of the permanent way, except the rails, fish-plates and fish-bolts, the price of which does not change with the sleeper; and not only to the first cost of all these but to their durability, for, according as they require renewal within a longer or shorter period, a certain amount should be added to the first cost, in order to provide a sinking fund for renewals, at the proper rate of interest. The weight and first cost of one mile of single track of various descriptions of permanent way (showing separately that of rails, fish-plates and fish-bolts) may be compared in the following table (see p. 40), made out from a paper issued by the Technical Section of the Government of India, Public Works Department, in 1890.

Against the original cost must be set the value of the old material: cast-iron pots and plates are worth a good deal as

WEIGHT AND COST PER MILE OF SINGLE TRACK OF DIFFERENT DESCRIPTIONS OF PERMANENT WAY IN INDIA.

Description.	Weight.		Total Cost delivered at Post in India.*	
	tons		rupees	
75-lb. F. F. rails, fish-plates, bolts and nuts	126·54	221·82	13,264	24,233
Transverse steel sleepers and keys	95·28		10,969	
75-lb. F. F. rails, fish-plates, bolts and nuts	126·54	253·13	13,264	21,549
Bearing-plates and spikes	10·97		2,272	
Indian timber sleepers	115·62		6,013	
75-lb. D. H. rails, fish-plates, bolts and nuts	127·48	350·48	13,372	33,600
Cast-iron (Denham-Olphert's) plate sleepers, complete	223·00		20,228	
75-lb. D. H. rails, fish-plates, bolts and nuts	127·48	314·63	13,372	24,678
Cast-iron chairs and spikes	58·59		4,495	
Indian timber sleepers and wooden keys	128·56		6,811	

* The total cost of English material includes cost F.O.B. in England, sea freight at 24*s.* per ton, insurance at 1 per cent. on prime cost plus sea freight, conversion into Indian currency at 1*s.* 4½*d.* to a rupee, and landing charges at 2 rupees a ton. Indian freight must be added. These figures must be accepted with caution, as the number of sleepers allowed per 30 feet rail is not the same in each case; but they enable us to make a tolerably fair comparison.

scrap: old wooden sleepers can be used for packings, hutting the other material—Great Britain, France and Belgium being decidedly in favour of wooden sleepers, while metal sleepers are generally in favour in Germany and Scandinavia.

The saving in maintenance of a metal sleeper will not, as a rule, include much reduction in the number of gangmen employed.

It will be seen that the choice of the material and description of sleeper depends upon many factors, and must be made after a careful consideration of the several and particular circumstances of each case. For instance, in regard to India, we may say that deodar from the Himalayas, creosoted pine from Europe, and the imported metal sleeper, meet in cost at certain points on a railway; that, even where the last is dearer, its longer life under well-known conditions will justify its adoption; that cast-iron sleepers can be made in the country, and the scrap utilised; that white ants will not attack teak or pyingado, and do not destroy even deodar, as a rule, until after it has done good service for several years; and that, when timber contractors and the Forest Department force high rates, we can fall back upon metal.

In calculating the life, and, therefore, the ultimate cost of sleepers, we can learn little from statistics. The average life of rails and sleepers is recorded without any details as to soil, hygrometric or other conditions, loads, speeds, grades, &c.; and no practical deductions can possibly be drawn from bare figures. Arithmetically, everything may be expressed with perfect accuracy, but a steel sleeper road, laid in a few miles of wet saline soil, will completely upset the average.

34.—Points and Crossings.

The object of points and crossings is to pass trains from one line to another.

The points, tongues, or switches, are short, tapering steel rails, so adjusted, each to its own stock rail, that, when one switch is pressed against its stock rail, the other switch is drawn away from its stock rail, and thus one line or the other is made continuous.

A pair of 12-foot points in use on the London and North-Western Railway, shown in Fig. 12, consist of—

2 tongue rails.
2 stock rails.
2 toe-chairs and keys.
6 slide-chairs, with bolts or studs and nuts, fastening the stock rail to the jaws of the chairs.
2 heel-chairs and keys.
2 connecting rods.
1 point rod, attached to one of the connecting rods and leading through rods and cranks to the lever which actuates the points.
1 tie bar, to keep the gauge just in front of the points.

The switch and stock rail are sometimes fastened together at the heel with a stock-wedge or heel-block between, and this arrangement assists in checking any tendency of the switch rails to creep.

The stock rail or side rail is, as a rule, straight or but slightly kinked, and the toe of the switch is housed under the flange of it. In some cases, however, as on the Great Western Railway, the side rail is cranked as much as $\frac{3}{8}$ths of an inch, and the switch, although stouter and stronger than usual, can

Switches and stock rails are usually made of ordinary steel rails, selected, cut and machined. After being tapered on both sides by planing, the switch is heated and set at the middle, to make the inner or running edge straight, unless it is a very long switch, and requires to be curved.

Too short switches are liable to tip up under the blows of trains playing on a loose heel. Their length should not, therefore, be less than the distance between two following wheels.

On the London and North-Western Railway a 9-foot switch is used with a 21-foot side rail, and a 12-foot or 20-foot switch with a 30-foot side rail, the length of the switch increasing with the number or acuteness of the crossing. The more usual lengths are 9 feet, 12 feet, and 15 feet, but on the Highland Railway we find them as long as 18 or 21 feet. The longer switches and easier crossings will, of course, be selected for facing points. In India we adopt shorter stock or side rails—an 18-foot stock rail with a 12-foot switch, and a 21-foot stock rail with a 15-foot switch.

The screw-coupled tie-bar, shown in front of the toe of the switch in Fig. 12, is provided at all facing-points on passenger lines and on the cross-over roads which are used by banking engines. Instead of gripping the rail underneath, the round bar may be bolted to the web of the rail. In some cases, instead of a round bar, a sole bar, with holes drilled through it to take the fastenings of the chair, holds the stock rail to gauge.

Points are described as facing or trailing, according as the train passes over them from toe to heel of switch, or from heel to toe: in other words, as the train approaches them from one line leading into two, or from either of two lines converging into one.

Facing points (as shown in Fig. 14) should be locked in position by a bolt passing through the stretcher bar; and should also be fitted with a locking bar to prevent the signalman from shifting them while a train is passing over them.

A right-hand set of switches is one which will turn a train entering them off to the right; a left-hand set, one which will turn an entering train off to the left. The right-hand switch (of either a right or left-hand set) is that one which turns a train into the right-hand line; the left-hand switch that which turns a train into the left-hand line. If we face the points, a turn-out to the right demands a right-hand set of switches; if we turn about and look from heel to toe, the right-hand switch is that on our right.

On minor lines and in goods yards the point rod is generally connected with a counterweighted ground lever, but point levers and signal levers in passenger yards are, on the more important railways, grouped and interlocked in a frame in a signal cabin. A few notes on this subject will be furnished later on.

A crossing in use on the London and North-Western Railway, shown in Fig. 13, consists of—

1 pair of wing rails, covering the nose of the crossing.
1 pair of check rails or guard rails inside the outer rails.
1 crossing, made up of a point rail and a splice rail.
6 crossing chairs.
8 check chairs.
2 bridge chairs.
Crossing blocks, check blocks, bolts and keys.

Crossings are also made of cast steel in one solid piece with the wings, and so designed that the upper and lower tables are

CHAPTER II.

PLATELAYING.

35.—Division of Labour in Platelaying.

THE platelaying of a new line of railway cannot be commenced until the banks and cuttings have been made up to the proper formation, the bridges completed (or temporary expedients arranged in their place), and permanent-way material collected at suitable depots.

The operations connected with the platelaying may be divided into three:—

(*a*) Conveyance of material to the working-point;
(*b*) Linking-in; and
(*c*) Lifting, straightening, packing and boxing.

Accordingly, the supervisional and working staff must be regularly organised in three divisions:—

(*a*) Material gangs;
(*b*) Linking-in gangs; and
(*c*) Lifting and packing gangs.

36.—Material Gangs.

These are engaged in unloading the material from trains and loading it on carts or trollies; in again unloading the material and distributing it alongside the line; and in clearing the line, as the working-point advances, of surplus material. The regular and continuous supply of material is, as already observed, of the first importance.

Rails should be loaded on two trollies, front and rear, in order that they may be more steadily carried over the new and rough road.

A platelayer should know how much of each kind of material an ordinary truck will hold. Thus, a ten-ton truck, on the 5′ 6″ gauge, will carry 33 or 34 rails (75-lb. section, 30 feet long) or 161 sleepers, whether the latter be of deodar wood or of steel, the weight of each being about 139 lbs. A mile of rails can be loaded into 10½ trucks, and a mile of sleepers into 11. In every alternate truck the rails should be packed up on sleepers or bolsters, so as to overhang those in the adjoining trucks, the rails in which should also be sufficiently raised to prevent them from resting on the floor of the truck in front and in rear.

37.—Linking-in Gangs.

A portion of these will first of all be engaged in placing approximately in position the material which has already been delivered alongside by the material gangs, laying the sleepers and rails as nearly as possible in place, and putting the fastenings where they can be got at readily.

The fish-bolts ought to be opened out, cleaned and oiled before they are laid out for the wrenchmen.

One line of rails, on a curve the outer rails, should be linked and spiked first. The first party of wrenchmen half-fish the rails, adjusting for expansion; while the rest complete the by a man with a bar to adjust the rail, the mate applied and removed the gauge, the spike was driven half-way, the gauge was again applied, and the spike then driven home.

The road is then roughly straightened, lifted and packed.

A clearer idea of the details of linking-in a new road will, perhaps, be obtained from the description of an actual day's work.

Let us suppose that a quarter of a mile of 24-foot flat-footed iron rails on wood sleepers is to be taken out and replaced by 30-foot flat-footed steel rails of heavier section on steel trough sleepers.

The new material has been carefully laid out on one side, so as to leave room for throwing out the old material on the other. Some of the rails had been sagged by careless handling or by being tipped up in short trucks, the ends of which could not be let down to allow the rails to lie flat. These have since been straightened in a portable rail-press, and all are now laid out in pairs, in two straight lines, at the edge of the ballast, the ends not touching, but having the proper clearance for expansion between them—one-quarter of an inch, or perhaps less—so that the new rails occupy the exact length required right along the line. On the slope of the embankment, opposite the centre of each pair of rails, lie the proper complement of steel sleepers, two pairs of fish-plates, and eight fish-bolts; the boxes of steel keys have been placed in convenient positions; and all the tools have been arranged ready for use at the foot of the slope.

The inspector has not more than 100 men, although he could find work for at least 250. He has to let a train pass at 9.30 a.m. before breaking the road, and must finish the job before 6 p.m.

Meanwhile, the men are engaged on the road already relaid. One mate and gang are rough-straightening; another mate and gang are finishing the straightening. One lifting gang is taking up the joints and middle; another is setting the road, putting a finishing top on it, and boxing up. The wrenchmen are tightening up the fish-bolts.

Another gang is stripping the ballast from the road which is to be renewed to-day, removing all but two fish-bolts at each joint, chipping sleepers to rail-seat level, so that the claw-bars may grip the heads of the spikes to be withdrawn, easing the spikes and splitting the fang-clips with a cold sett and heavy hammer. Boys are engaged in picking up the fastenings which have been taken out, oiling fish-bolts, chalk-marking the sleeper distances on the new rails, &c. At the end of the portion of road to be renewed are some 15 or 20 pieces of rail of different lengths, from which closers may be selected without having to cut and waste rails. The ends of these are already drilled to take the fish-bolts ; and, if the closers are of various lengths, say from 4 inches to 7 feet, with two pairs of slotted fish-plates most gaps may be closed without cutting long rails or pulling back the old road beyond. When very short pieces are dropped in, and fish-plates with long slots used, precautions should of course be taken to strengthen such weak joints, by placing pieces of old sleepers under them, until they are removed in continuing the renewals the next day.

After the last train has been cautiously passed over the partially-dismantled road, the closers and specially-made fish-plates (connecting the old and new rails) are removed and trollied to the further end, the remaining fish-bolts taken out, and the outer spikes drawn.

The old rails are then pinched out, lifted off with the rail-nippers or tongs, and deposited on one side.

After the wooden blocks have been removed, and the rail has been dropped into place, an expansion-wedge or distance-piece is inserted between the ends, and the rail driven close up. One of the sleeper-keys at each joint must always be driven before the fish-plates are fitted on, as it cannot afterwards be driven from the fish-plate side.

The opposite rails are then levered on to the sleepers, pinched into the lugs, and hammered home against the inner lugs, while a man at the end of each sleeper levels it up to the rail.

The wrenchmen now half-fish the joints with two bolts (or even one only if there is much press for time) to hold the wedges in. They check the squareness of the joints with a set-square, and the expansion-wedges are allowed to remain in until the fish-plates have been completely bolted up for a distance of eight or ten rail-lengths ahead by the following wrenchmen.

The keys are then driven. Some of the lugs having perhaps got bent, it may be necessary to drive a chisel first and knock it out before the key can be fitted. The chisel has been so shaped that it will also serve as a drift for the fish-bolts. Impracticable keys are at once picked out to be straightened, or to have the burrs chipped off with a chisel, but, as a rule, it is found that the keys drive easily without using the drift-hammer.

It now only remains to put in the closers at the end of the relaid track, and to pack and straighten the road before passing the first train over it.

38.—Number and Distribution of Workmen.

Whatever the number of men employed may be—and that must vary with circumstances and the speed with which the work has to be pushed on—it is essential that the men be thoroughly well organised and supervised; every man should have certain work to do, and there should be no over-crowding or confusion.

Supposing that the material is brought up and laid out rapidly and continuously, the speed of platelaying is only limited finally by the time required to link two pairs of rails together, and the number and distribution of workmen depend upon this entirely.

While it might take three minutes to link-in a pair of 21-foot rails, a gang of ten men could not lift, pack, fill in, straighten, and box up the same length of road in less than fifteen minutes; and the faster the linking can be done the more men will be required to lift and pack within the same time. Although no exact proportions, therefore, can be fixed, it may be said generally that the material gangs and the lifting and packing gangs ought to be at least three or four times as strong as the linking gang, if all the operations are to be carried on at an even rate.

The Merv-Charjui section, 154 miles long, on General Annenkoff's extension of General Skobeloff's Trans-Caspian Railway was laid in 1885 at the rate of 38½ miles per month. In 1879, the Sibi Railway, 133 miles in length, was put down at the rate of 40 miles per month, and this is probably the smartest piece of work of the kind on record: when the platelaying was in full swing the rails were linked together at the rate of two pairs per minute, whereas, at first, it took two minutes to join up one pair.

In a paper read before the United Service Institution at Simla, Mr. J. R. Bell expressed his opinion—based on his experience on the Sibi Railway—that a month was required to collect labour and get into full swing, after which 4 or 5 miles a day might be the utmost limit of progress. Working on the "split-lead" as well as "single-lead" system was tried both in Russia and England, but the former was abandoned owing to the difficulty of carrying material to a second party beyond. The road-bed on the Sibi desert was prepared by ploughing a width of 100 yards, to loosen the earth for the packing gangs.

As an example of platelaying in mountainous country, he mentioned the line between Rindli and Darwaza, which was carried 69 miles along the bed of the Bolan, rising over a vertical mile, in 10 months.

Unless time is the chief consideration, however, great care and accuracy in laying a new track will be amply repaid by easier maintenance afterwards, and far longer life of material. The platelayer's chief object should be to lay the road in a workmanlike manner, rather than to rush it through. His rails should be straightened or curved, as required, his sleepers laid square and properly spaced, the gauge exact, expansion carefully allowed for, his bolts cleaned and oiled, and every preliminary arrangement made to ensure good platelaying.

Referring to the actual platelaying only, the following, including bheesties, would probably be able to link-in and finish one-quarter of a mile of double-headed rails on cast-iron pot sleepers per diem, on the 5′ 6″ gauge:—

Fixing tie-bars	5
Linking-in	65
Filling sand for lifting and packing up	65
Lifting and packing	50
Levelling sand and putting on a 3-in. top dressing of ballast	65
	250

For such a gang the following tools would be required:—

Bars, large	20
Bars, small	10
Baskets	150
Chisels (for splitting cotters)	5
Hand hammers	5
Keying hammers	5
Lifting levers	2
Phaoras	125
Pot rammers	100
Sling-hooks (and bamboos)	12
Spirit level	1
Straight-edge with height boards	1
Wooden beaters	20
Wooden square	1
Wrenches	4

Between 1888 and 1890 very heavy renewals were carried out on the writer's division of the North-Western Railway of India. The old road consisted partly of D.H. rails in cast-iron pot sleepers, and partly of F.F. rails on wood sleepers. These were replaced by heavier F.F. steel rails, either on wood or on steel sleepers.

Mr. Campion, one of the inspectors, found that he could relay, without interruption of traffic, a quarter of a mile a day, and he furnished the following details to 'Indian Engineering' (issue of January 31, 1891) and to the writer.

A gang of 55 coolies having previously opened out the road, the first distribution of his men was as follows:—

Gangs.	Number of men.	Work on which employed.	Tools, &c., used.	Time occupied, in hours.
A	8	Unfishing joints	8 spanners	2
B	4	Clearing spike-heads	4 adzes	1½
C	4	Drawing coach-screws	4 spanners	1½
D	4	Breaking jammed bolts	4 hammers	1½
E	12	Drawing spikes	12 claw-bars	1½
F	8	Throwing out rails	8 tommy-bars	2
G	1	Turning over sleepers for easy removal	1 pick or bar	2
H	6	Throwing out sleepers	..	2
I	26	Dressing road for new sleepers	6 pickaxes and 20 shovels	2
J	18	Laying out new sleepers	..	2½
K	5	Roughly spacing and aligning sleepers	100 ft. cord	2½
L	4	Boys collecting fastenings	Baskets	1½
	100			

For the second series of operations the same men were distributed as shown on p. 53.

Each set of four forward spikers was provided with 2 hammers and 3 bars; two men having 2 hammers and 1 bar between them, and the other two holding up the sleeper with their bar.

Nine of the ten men spiking the opposite line of rails were divided into 3 sets of three men, each set having 1 gauge, 1 hammer and 2 bars, while the tenth man with a bar assisted the mate in adjusting the rail to gauge. The mate took this man on ahead with the first set of spikers, to shift the joints and middles of rails to gauge prior to spiking them. The two following sets completed the job.

Gangs.	Number of men.	Work on which employed.	Tools, &c., used.	Time occupied, in hours.
E	12	Placing rails on sleepers	6 rail nippers	2
K	3	Inserting distance-pieces and roughly straightening	Expansion wedges and 2 bars	2
C	4	Roughly fishing joints	2 crowbars and 8 spanners	2
A	8	Screwing up joints		2
B	4	Correctly spacing sleepers	Bars	2
G	1	Marking one line of rails for sleepers	Chalk and rod	2
K	2	Marking opposite rails	T square and chalk	2
F	8	Spiking forward the leading or line side rails, in two sets	6 bars and 4 hammers	2½
D H	6 4	Spiking the opposite or gauge line of rails, in three sets	3 gauges, 7 bars and 3 hammers	2½
L	4	Distributing spikes	Baskets	2
J	10	Lifting	Height board, level, &c.	4
I J	12 8	Filling in ballast for packing ..	Phaoras and baskets	5½
I	14	Straightening	Bars	5½

Any spare time was finally occupied in packing.

A sub-inspector, with 25 men, following up the linking gangs, repacked and roughly filled in the new road, doing a quarter of a mile a day.

The following tools, &c., were provided:—

12 dozen augers, ⅝ in.
40 claw bars, steel-tipped.
30 small bars "
250 phaoras.
200 beaters.
500 phaora handles.
500 beater handles.
12 spiking hammers, 8 lbs.
50 ash-shafts for ditto.
6 sledge-hammers.
1 small anvil.
1 hand-bellows.
1 water-trough.
1 gross fog signals.
1 measuring tape, 100 ft.
1 rule, 2 ft.
2 sets flag signals.
4 large red flags.
4 hand lamps.
2 large signal-lamps.
1 set height and sight-boards.
2 spirit levels.
20 lbs. of cord.
1 T-square.
1 rod, 15 ft., for opening sleepers.
2 lbs. chalk per mile.

12 spanners for old bolts.
12 spanners for new bolts.
12 rail nippers.
200 baskets.
6 dozen boxes of matches.
4 lbs. oil per mile.
80 lbs. charcoal per mile.
Iron of sorts for repairing tools.
1 jim crow.
1 rail press.
2 ratchet braces and bits.
1 dozen chisels.
1 drilling post.
2 direction boards.

All the sleepers were notched and bored to a template beforehand; a carpenter and coolie could do 50 per diem.

Two, and sometimes three, inspectors (including Mr. Campion) were simultaneously renewing the line on different sections of the division. Their methods differed considerably; but each was allowed to pursue his own, subject to no other interference than an occasional suggestion, and the results were in each case most satisfactory.

On the metre gauge, Mr. H. G. Arnott, assistant engineer (who worked with the writer for several years), carried out very rapid renewals, with a large number of men distributed as follows:—

Workmen, how employed.	Mates, 1st class.	Mates, 2nd class.	Men.	Boys.
Cutting out fang-bolts and loosening fish-bolts	..	1	34	..
Carpenters with the above	..	..	2	..
Blacksmiths „	..	..	8	..
Hammermen „	..	..	8	..
Laying rails in position	..	1	16	..
Trollying sleepers and small material	..	1	20	..
Opening out and fishing rails and adzing sleepers	1	..	48	..
Carpenters with the above	..	..	6	..
Digging out ballast for joint sleepers	..	1	12	..
Spacing and spiking sleepers	1	..	84	..
Packing—1st gang	1	..	70	..
„ 2nd gang	..	1	30	..
Trollying old material to gate lodges	..	1	20	..
Straightening and jim-crowing	1	..	10	..
Picking up renewed small material	..	1	..	10
Repairs of tools, handles, &c.—carpenters	..	..	2	..
„ „ blacksmiths	..	..	2	..
„ „ hammermen	..	..	2	..
Signalmen	..	1	6	..
	4	8	380	10

In addition to the above, there were a tindal and 10 men with five carts for shifting camp daily, 8 bheesties or watermen, and 4 chokedars or watchmen in charge of tools and camp. The number of men employed was large, but—after a week—the renewals proceeded steadily at the rate of 1¼ mile a day, although the line had to be closed up four times daily to allow passenger trains to pass.

In laying a new road on the metre gauge with F.F. rails and wood sleepers, the same engineer made the following distribution:—

Workmen, how employed.	Mates.	Men.
Loading rails, sleepers, and small material	1	75
Sleeper trollymen	1	24
Rail ,,	1	18
Rail carriers for forward work from tip	1	36
Small material trollymen	1	6
,, carriers, front		4
,, ,, rear		4
Sleeper placers	1	6
Rail placers		6
Sleeper squarers and rail markers	1	8
Spanner men, front		10
Spikers, front	1	18
Spanner men, tighteners	..	4
Rough straighteners	1	4
Full spikers, rear	2	60
Rough packing	2	40
Straighteners	1	4
Full packers	3	80
Straighteners	1	4
Boxing-up gang	1	80
Jim-crow gang	1	4
Ratchet gang	1	4
Rail-cutting gang for curves	1	8
	22	507

There were also 10 bheesties or watermen, 10 carpenters, and 5 smiths.

With the inspector were two sub-inspectors, one in advance with the linking party, and the other (and better of the two) with the finishing and packing party.

One gang—30 or more rail-lengths ahead—half-fished the joints, and spiked four sleepers per pair of rails. The next gang completely fished the joints, and spiked the remaining five sleepers. A mate followed these with a gang for rough straightening and packing; another gang fully packed the road. Then came a straightening and jim-crow gang, who also tightened up loose bolts and drilled bolt-holes in cut rails, where required. Lastly came a strong gang of coolies, to box and trim the ballast. The small material carriers, forward and rear, supplied the wrenchmen who were half-fishing joints in front, and those who came after them to complete the fishing.

With this number and distribution of men a mile or—when the work was in full swing—a mile and a half of platelaying could be done per diem.

In England, perhaps, not more than 25 or 30 minutes—instead of, as in India, 3, 4, or 5 hours—can be snatched between trains for occupation of the line and relayings, and not more than 5 rail-lengths relaid at a time.

All materials are got ready, the ballast is cleared to the bottom of the sleepers, two out of four fish-bolts at each joint are removed, and every alternate chair-key is taken out.

As soon as the train has passed, the remaining chair-keys are knocked out, the rest of the fish-bolts removed, the rails taken out, the old sleepers turned over, so that they may easily be lifted and carried away, the old bed is picked up, and a fresh bed dressed off with shovels.

Then the new sleepers, with chairs fixed on, are placed—the six-foot way between rails being left clear—a boy lays out the keys, fish-plates and bolts, so that they may be at hand, the new rails are put in, the centre key of each rail is driven—the men holding the rail with bars against the inside jaw of the chairs—the two middle fish-bolts at each joint are fitted, the expansion-wedges are dropped between the ends of the rails, the keys of each alternate chair are driven—one man levering up the sleeper, while the other drives the key—and a train may then be passed over at 10 miles an hour.

This might be done by a ganger, 25 men and a boy.

39.—Lifting and Packing Gangs.

These will perfect the operations of straightening, lifting and packing.

The first lifting gang will level up the joints, the height board being accurately placed about 100 feet ahead of the previously-adjusted sighting point. The second party will pick up and level the intermediate sleepers.

Four men should be told off to a pair of rails, all four packing a sleeper—front and back, right and left—at the same time, so that the sleeper may not be forced out of place during the operation.

Trains should be passed over the new line at moderate speed until the road is well consolidated.

The rails should be in line and level before the fish-bolts are tightened up; the strain of bringing into exact position two adjoining rail-ends should not be thrown upon the fish-plates and fastenings.

40.—Duties of a Permanent-way Inspector.

We now come to the matter of maintenance, and the permanent-way inspector must remember that he is personally responsible for the state of the road.

It should be his object to make the road both safe and elastic; to effect this as economically as possible; and, only when he is sure that he has a really good road, to make it look like one.

He must personally superintend renewals, utilising his material to its utmost; and either he or one of his sub-inspectors should always be present when a rail is being renewed.

The inspector has to keep an account of all material laid in the line, taken out and stacked, or received from stores and held in reserve for purposes of renewal. The less writing-work he has to do, however, the better.

He should regularly and minutely examine all bridges and culverts, points and crossings, signals, &c., so that he may be able to certify that they are in good order; and he should see that side drains and waterways are cleared of long grass and rubbish.

The inspector ought to trolly over the whole of his section at least once in three days, carefully noting all bad rails and sleepers, loose or broken fastenings, and other defects. With this object, in boxing the ballast, spikes and other fastenings are to be left bare. He can best detect weak places and feel the quality of his road when travelling on the engine, and this he will frequently do, either going or returning.

When he has to take his trolly off to let a train pass, he should observe how the train affects the road, and will often thus detect weak joints and loose sleepers which would otherwise escape his notice.

He will of course stop at each gang to give orders, and should occasionally stay with them some time, direct their work, and see whether the mate understands his duties.

When arranging for any special work, he should have a sample piece done, time the men, and thus judge the time required to complete it.

His inspection should be made irregularly, so that the gangs may not know when to expect him.

He should report all accidents to the officials concerned, and bring to the notice of the assistant engineer any important or dangerous defect in the permanent way, bridges, &c.

The inspector should get thoroughly acquainted with his men, and know exactly what each man can do.

When a train is approaching, the gangmen should form up on one side of—and at right angles to—the line, so that the inspector or engineer, if he is in the train, may see that all are present.

41.—Duties of a Sub-Inspector.

It is the duty of a sub-inspector to carry out the inspector's orders implicitly. He will have charge of a sub-section of line, and must be present whenever a rail is being changed or heavy lifting being done, giving due notice and arranging danger signals.

He should always carry with him on the trolly a supply of fog-signals, two large red flags, hand lamps, spanners, two chisels, a hammer, a ratchet-brace and bits, a gauge, and a telegram-book.

42.—Maintenance Gangs.

On the 4′ 8½″ gauge we might have four or five men, including the ganger, on a 3-mile length of single line or on a 2-mile length of double line.

In India, an average over the whole single line of two men per mile (including the keymen but not the mates) on the metre gauge, or of three men on the 5′ 6″ gauge, should be sufficient to maintain the permanent way when once it has been got into working order.

On the metre gauge a mate and gang could maintain at least 3 miles; while, on the 5′ 6″ gauge, more men being required together to handle the heavier material, a length of 4 miles would not be too much, and would place 12 men under the control of each mate.

The headquarters of the gang should be as nearly central as possible, and close to the line.

43.—Duties of a Mate or Ganger.

The mate has direct charge of all the ordinary work of maintenance. He has to take out and replace all defective material, to stack old material at a sufficient distance from the line, to patrol the line in time of danger from rain or any other cause, to watch the action of water-courses in flood, to see that signal and telegraph wires are not obstructed in any way, to keep all water-channels open and clear them of rubbish, to repair the fencing, to clean the working parts of points and signals, to take charge of all tools and materials in his length, &c.

With a section of 4 or 5 miles the mate, if his headquarters are fairly central, should generally be able to walk over his beat, half one day and half the other. He can scarcely do more than this, for the gang cannot be trusted to work by themselves, and his place is with them.

When his line is in fair condition he should make his men work—week and week about—from one end or the other.

44.—Duties of the Wrenchman or Keyman.

The keyman is the mate's right-hand man, and generally able to take up his duties in his absence. As a picked man he usually gets a little more pay than the rest of the gang.

Starting early in the morning, the keyman should go over the whole of his beat—walking down one side of the track and returning on the other—driving loose keys and spikes, tightening loose bolts, and replacing broken fastenings. He should then begin at a certain point, and do a quarter of a mile or so thoroughly. He should bring all defects to the notice of the ganger, who, if he cannot go himself, may send a couple of men with the keyman, if necessary, to pack loose sleepers.

The keyman on a pot or chair road carries the following tools and fastenings with him:—

1 key-hammer, 6 lbs. or 7 lbs. in weight.
1 large spanner.
1 small spanner.
6 fish-bolts and nuts.
6 wooden keys.
1 small hand-chisel.
1 steel scraper for cleaning chair-seats.

On a road of flat-footed rails on wooden sleepers, the wrenchman would carry the following :—

1 hammer, about 4 lbs. in weight.
1 spanner.
1 small hand-chisel.
6 fish-bolts and nuts.
6 spikes.

It is as much as he can do to work through the whole beat properly, and he will seldom be able to return to work with the gang. Indeed, the more he is kept to his particular duties the better, instead of being encouraged to rush through his length and rejoin the others. If he goes through rapidly and carelessly, he will pass a good many loose keys, split others with a hurried stroke, and take little notice of loose bolts and broken fish-plates.

45.—Platelayers' Tools.

On the 4′ 8½″ gauge, a ganger and five men, maintaining a road consisting of B.H. rails in chairs on wood sleepers, might require following tools, &c :—

6 beaters.
6 bars (1 claw).
5 spanners.
3 hammers.
1 lever pole.
1 set augers.
1 spirit level.
1 straight-edge.
1 axe.
1 adze.
1 drill frame and drills.
1 lorry.
2 sets signals.
2 hand lamps.
1 jim crow.
2 gauges.
2 plug cutters.
1 plug cup.
1 plug drift.
2 yard brushes.
1 yard scraper.
1 hand hammer.
1 lifting jack.
1 file.
1 chisel.
1 barrow.
2 oil feeders.
1 oil can.
1 satchel.

The following lists give the full complement of tools required (1) for a gang consisting of one mate, one keyman and eight men, on a 3-mile length, 5′ 6″ gauge, B.H. rails, and cast-iron pot sleepers; and (2) for a gang consisting of one mate, one keyman and eleven men, on a 4-mile length, 5-foot 6-inch gauge, F.F. rails, and wooden sleepers:—

Tools and Appliances.	B.H. Rails and Pot Sleepers.	F.F. Rails and Wooden Sleepers.
Augers, $\frac{1}{2}$ in. or $\frac{5}{8}$ in.	—	2
Baskets	8	11
Beaters	2	11
Book of railway regulations	1	1
Claw bars and crow bars	6	8
Cold chisel	1	1
Flag signals	2 sets	2 sets
Fog signals	12	12
Gauge	1	1
Hand hammer	1	—
Hand lamps	2	2
Jim crow, or rail straightener	1	1
Keying hammers	2	—
Lifting lever	1	1
Munj rope	100 feet	100 feet
Phaoras	8	11
Ratchet brace and bits	1	1
Screw wrench	1	1
Sighting boards	2	2
Sling hooks	2	2
Spanners	2	2
Spiking hammers	—	2
Spirit level	1	1
Steps, or inch-boards	2	2
Straight-edge	1	1
W.I. punners	8	—

The tools should be collected and counted by the mate every night, and kept in a locked tool-box.

It is scarcely necessary to say that gauges are apt to wear loose, and should be tested every two or three months by the inspector.

A short steel-pointed chisel-bar—or "tommy-bar"—is a useful tool, and very handy for turning over rails when loading, unloading, or shifting them. For lifting and carrying ls a sort of pincers, gripping the head of the rail and having horizontal handles, will be particularly useful in platelaying. With six such nippers, twelve men will pick up or lay down a 30-foot 75-lb. rail both quickly and gently, and carry it with the greatest ease. In station yards, where a great deal of heavy work in connection with points and crossings has to be done, a rail and crossing lifter will be found useful: with such a lifter five men can do the same work as twelve with a lever. While the unnecessary multiplication of tools is to be avoided, no tool need be regarded as superfluous which saves time and labour, and enables the workmen to handle material more easily and less roughly.

46.—Maintenance of Rails.

When one edge of the head of a rail is worn, the rail may be turned end for end in its place, or shifted to the other side.

A double-headed rail, the upper table of which is worn, may be inverted, unless the lower table has been corroded in brackish soil or dented by the chairs. It will at any rate serve to put in a siding, from which good rails may often be taken for the main line. Where double-headed rails are used in England, it is a frequent custom to invert them every two years.

Double-headed rails frequently become chair-marked through neglect, the chair-seat not being kept free from rust and dirt. Some platelayers occasionally unkey and raise the rail, clean the seats thoroughly, replace the rail and drive the keys—first those in the middle, next those at each end, and lastly the intermediate ones. In putting in a new rail, also, the same order should be followed—the key of the middle chair or pot should be driven first, while the rail is held up with bars against the inside jaw of the chair or pot. Some of Greaves' oval pots were fitted with wooden packing-pieces, to prevent chair-marking, but the result was not satisfactory.

Turned rails do not wear anything like so well as the original upper table.

Rails which are worn or split at the ends may be cut and used as closers or check-rails. Every possible use ought to be made of a rail before it is finally rejected as unserviceable. Rails unfit for main line are generally good enough for sidings, and an economical platelayer will make such interchanges as much as possible before calling for new rails.

When a rail begins to fail, a stake is driven at the side of the line, and the deterioration of the rail carefully watched until it is necessary to remove it.

Rails should not, in the hot weather, be taken out and replaced during the heat of the day. If, from insufficient room for expansion, the inspector thinks that the rails will close in somewhat, when one is taken out, he should have the rails pulled back from either side the day before. Otherwise, he may have to use a cut rail. Inspectors have sometimes ten or twenty rails to change in one day at different places. Accordingly, fish-bolts and nuts are unscrewed, cleaned, oiled and replaced, a day or two before the new rail is to be put in, so that the actual renewal may be easily and quickly done.

Either the inspector or sub-inspector must invariably be present on such occasions, and see that the line is protected by hand and fog-signals on each side. The station-masters on each side should be advised, and drivers warned to look out for signals.

Before breaking the road the inspector should make sure that the new rail is of the exact length required, with sufficient clearance for expansion.

47.—Fishing the Rails. Expansion.

When two rails are being fished together, a small space is left between them to allow for expansion. This space may be from one-eighth to one-fourth of an inch, according to the length of the rail, the extreme variations of temperature, the season of the year, and the time of day when they are linked in. In England at ordinary temperatures, a clearance of one-eighth or three-sixteenths of an inch is allowed between the ends of 30-foot rails. In India, during the cold weather, as large a clearance as a quarter of an inch may be required to allow for the maximum expansion in the hot season; the hotter the rails are when laid, the less clearance need be given, and *vice versâ.* Wooden or angle-iron wedges or iron rings of different thicknesses must be placed between the ends of the rails while they are being fished, and are easily removed with a bar when the bolts are screwed up.

If too much space be allowed for expansion, the fish-plates and bolts will often snap in the cold season, and the bolts may be so jammed against one side of the holes that it will be difficult to take them out, if required. To lessen the space, the bolts should be slackened during the hottest time of the day, so that the rails may expand freely; the bolts may then be screwed up again.

On the other hand, if too little space be allowed, the rails will either buckle or creep. Should they buckle, the road may be temporarily adjusted to a reverse curve until there is an opportunity of opening out the road, taking out the fish-bolts, oiling them, and replacing them on one side of the joint only, loosening the chair-keys, drawing the rails sufficiently apart to admit the expansion wedges, removing one pair of rails, and replacing them by short rails as closers. The wedges should not be taken out until the rails have been eased for a considerable distance ahead.

Until lately, 30-foot rails have been the longest in common use; but, as before mentioned, 40-foot rails are now being introduced in India. The longer the rail, the heavier it is, of course, to handle, and the more liable to get sagged when carried by railway (unless loaded in special trucks), and the more clearance is required for expansion—so that the joints are more liable to sink, and, consequently, the ends of the rail to be spoiled.

The fish-plates should not be too long, not only because—if screwed up too tightly—they check the expansion and contraction of the rails, but also because they prevent the adjacent sleepers from being placed close enough to each other to support the joint efficiently.

Fish-bolts should be cleaned and oiled—in England they are generally dipped in tar—before being put in, and they should not be screwed up too tightly, not only lest they should break, but because the tight lateral grip of the fish-plate may prevent free expansion, and either cause the rails to creep or buckle.

Fish-bolts are frequently damaged by the use of too long a spanner, or by neglecting to oil them before screwing or unscrewing them.

When a new rail is put in between two old ones, the heads of which are worn down at the ends, it may be necessary to put in liners or packing-pieces to raise the latter.

On a curve the inner rails follow a necessarily shorter line, so that the inner rail-joints tend to get ahead of the outer joints. When this lead is as much as 2 inches, a rail cut 4 inches shorter may be put in on the inner side. In this way the inner joint will be thrown 2 inches behind the outer, and twice the distance will have to be covered before the lead of the inner joint is again as much as 2 inches and another cut rail is required. If the curve be a short one, we need only cut off double the lead at the centre of the curve.

When a fish-plate is found to be broken and another is not immediately at hand to replace it, the joint should be temporarily supported by a piece of an old sleeper or other packing.

A few engineers prefer to "stagger" the joints, especially on sharp curves; this arrangement was tried several years ago on an Indian railway, but the result was not considered to be satisfactory.

Rail-joints are to be avoided as much as possible on small open top or girder bridges, or where a check-rail is to be put in.

48.—"Creep" or "Travel" of Rails.

This is one of the greatest difficulties with which the engineer and platelayer in India have to contend, and a most troublesome problem to deal with.

The crux of the whole matter lies in the too tight lateral grip of the fish-plates, which prevents each rail from expanding independently, and causes a "creep" to be rigidly transmitted along the line of rail in the direction of least resistance. If the sleepers are firmly anchored and the fastenings hold the rail so that it cannot slide on them, the rails tend to buckle; if not, they must creep. Sometimes this tight frictional grip follows from the particular form of the rail and fish-plate. The latter may be too long, or else, instead of only being in contact under the shoulder and upon the foot of the rail, it may fit closely to the web also, so that when screwed up it presses tightly against a large surface of the side of the rail. But the chief fault will often lie with the adoption of a section of rail having too great a fishing angle—in other words, the slopes of the upper and lower shoulders are not flat enough. In this case the fish-plate does not form such a direct support, and the bolts have to be tightly screwed up. The angle between the fishing-planes of English rails is frequently as wide as 50° or 60°, but should not be more than 30°.

When, however, we come to inquire in which direction the creep takes place and why, it is almost impossible to give a satisfactory reply. On a double track the tendency of the creep will probably be in the direction of the traffic on each road; on a single track in the direction of the heavier traffic, or from a higher to a lower level.

Moreover, this general movement or ploughing up of the rails by heavy traffic in one direction or the other will almost invariably affect the right and left lines of rails unequally, so that the joints are thrown out of square to a serious extent. Not only so, but the right and left-hand rails often travel in opposite directions.

Wherever practicable, keys should be driven in the same direction as the train travels. This cannot be done when the jaws and keys are tapered—unless, as on the Great Indian Peninsula Railway, the jaws are right and left-handed—and in this case, the resistance to movement being of the nature of a couple, the effect of expansion or contraction must tend to back and loosen the keys on one side, so that the rails are liable to travel in opposite directions. In England the jaws and keys are parallel, and the latter may be driven in either direction—on a double line in that in which the train travels—and, at joints, the keys may be driven towards the end of the rail, which enables the joint sleepers to be spaced as near to each other as will allow of easy packing, and thus materially relieves the strain on the fish-plates.

Steel sleepers are, perhaps, best able to resist the creeping movement, for their sharp edges prevent them from sliding on the ballast, and the rail is held very tightly by the lugs and keys. Here, therefore, the tendency is to buckle, and it is often difficult to keep a perfectly straight road, however heavily ballasted.

Wood sleepers move more easily, but, if they hold, angle fish-plates with notches to hold the heads of the spikes at the joint sleepers will prevent the rail from sliding on the spikes. This will stop creep on single lines, but on double lines it is also advised to fasten the joint sleepers to the next and, perhaps, others with wood or iron bar fastened down to the sleepers, or else to fix struts between them.

The rounded shape and smaller surface of frontage of pot sleepers afford the least resistance of all to the creep movement, but supposing them to stand their ground, the whole matter depends finally upon good keying.

If creep be allowed to accumulate, its correction becomes a tedious and costly operation. The fish-bolts for some distance have to be taken out, oiled, and replaced, the rails to be pulled square in opposite directions, and one pair to be taken out and replaced by two cut rails as closers.

Little more has been done, it must be acknowledged, in the preceding remarks than to set forth the difficulties and complications which beset the question of creep. Scarcely a single explanation can be put forward in any one case which is not apparently contradicted by the opposite circumstances of another.

49.—Maintenance of Wood Sleepers.

The guard sleepers—those next to the joint—should be spaced closer together than the others, and it would be as well also to have the intervals between the guard and second sleepers, and between the second and third from the end, somewhat less than between the others.

On the London and South-Western Railway, for example, with 11 sleepers to a 30-foot rail, the space between the guard sleepers is 2 feet 2 inches, the next interval is 2 feet 5 inches, and the rest are 2 feet 10½ inches. On the Midland, with 11 sleepers to the rail, the space between the guard sleepers is again 2 feet 2 inches, but the second interval is only 2 feet 3 inches, the third is 2 feet 9 inches, the fourth 2 feet 11 inches, and the rest 3 feet. On the London and North-Western Railway, with 10 sleepers to a 30-foot rail, the space (including one-eighth of an inch for clearance) between the guard rails is 2 feet 4¼ inches, and all the remaining intervals are 3 feet. With a marked rod there is no difficulty in spacing the sleepers as required.

Sleepers should be laid with the heart-side downward.

For double or bull-headed rails the sleepers are adzed on the sap-side just enough to give the chair a good bearing, are bored right through for the fastenings, are creosoted, and are then sent out with the chairs already fixed on; or the chairs may be fitted on at site. For flat-footed rails the rail-seats of the sleeper are adzed to a slope, so as to give the rail a tilt inwards of 1 in 20 to fit the coning of the wheel-tyres; this may be accurately done and the holes for the dog-spikes may be drilled correctly, before the sleeper is sent out, if a proper template be applied with holes through which the auger may be passed. When bearing-plates are used, the tilt is given to the rail by the plates, and (as with chairs) all that is necessary is to level and dress the portion of the sleeper on which they rest. All holes for spikes, &c., must be bored right through the sleeper. An auger of rather smaller size than the required hole should be used for deodar or other soft wood, so that the spike, when driven, may fill the hole completely. If the point of the auger will not hold, it should be oiled, not forced.

In Article 37 the method of spiking down a flat-footed rail to wood sleepers is briefly described. The guard sleepers should be spiked first, and then the intermediate ones. The rectangular dog-spikes must be driven vertically and square to the rail. Should the sleeper be of very hard wood, liable to split, the spike may be lubricated with soap before it is driven. In applying the gauge, care must be taken to place it at right angles to the rail on the straight, and normal to the rail on a curve.

When putting in a new sleeper on a chair road, the key of the chair is first driven tight, the sleeper is then placed evenly under the chair—square to the rail and properly spaced—and is firmly held up to the chair with crowbars, while the holes are bored and the spikes or trenails driven; it is usual to tar the heads of the latter before they are used.

Bearing-plates and dog-spikes make an excellent fastening for flat-footed rails, but, unless the traffic is fast and heavy, it will generally be sufficient to use the bearing-plates at joint sleepers only on a straight road, provided that the sleepers are of good quality.

When a sleeper is no longer fit for use at a joint, it may still do service as an intermediate. The joint sleepers are the most severely tried, owing to the joints, however good, yielding more than the body of the rail; the middle sleepers next require careful attention; the remainder are less important. It is in this order that the renewals of sleepers, therefore, should generally be carried out, rather than in continuous lengths; and economy can be secured by shifting partly worn sleepers from one position to another of less importance.

It is seldom feasible to turn over a sleeper in India, for the under side is not only torn by sharp-pointed beaters or by the ballast-packing, but often partially destroyed by white ants, even while the top is still fairly good.

If the bases of chairs do not cover a sufficient area there is a tendency to cut into the sleeper, the more so as the long edges of the chair run in the direction of the wood-fibres. If, however, the keys are kept tight and the ballast is sound and well packed, there will be less tendency to rock, and the chairs will not dent the sleepers so badly. Even when thus injured the sleepers will serve their time, if undisturbed. When a key is found to be slack, the chair-seat ought to be thoroughly well scraped and cleaned before the key is driven tight again.

All old spike-holes should be filled with tarred wooden plugs, neatly driven in. When the spike-holes are badly worn or rotten, the sleeper may be shifted a little transversely, so that new holes may be drilled. But if only one chair on a sleeper requires renewal, the old spike-hole should be plugged and re-bored for the new chair, the opposite chair not being touched.

When a new sleeper is put in, the old bed of ballast should be beaten up first, and the boxing should not be filled in for some days, during which the sleeper may require a little packing.

Sleepers which are getting into bad condition should not, as a rule, be covered over with ballast, but exposed until it is necessary to remove them. In a dry district, however, this may not be advisable, for fear of the sleeper being burnt by droppings from the fire-box of the engine.

Wood sleepers should be opened out for inspection after the rainy season, and will thus, moreover, be thoroughly dried.

When sleepers get out of square the spikes should be drawn, the sleepers replaced at right angles to the rail, the gauge applied, and the sleepers respiked.

If a loose sleeper is neglected for some time, the rail will begin to fail at that place; every train will drop heavily on the loose sleeper and aggravate the mischief; and the rail, which might have lasted for years, is rapidly spoiled. While working regularly through his length, therefore, the mate should also attend to these isolated cases of loose sleepers. The gang can pack a certain portion of road, say a furlong, in two days. On the third the mate or wrenchman should take one or two gangmen over the whole length to pack loose sleepers, while the rest box and dress the ballast.

Old sleepers, when taken out, should be piled in small stacks at some distance from the line and from each other; earth should be thrown on the top of each stack, and the ground close by cleared of grass or other rubbish liable to catch fire from sparks from a passing engine.

In laying bridge sleepers, the distance between girder and rail is to be carefully measured from point to point. The sleepers should then be cut accordingly on the lower side and marked for their places, so that differences due to camber of girder, rivet-heads, and cover-plates may be allowed for.

50.—Lifting, Packing, and Boxing.

On the 4′ 8½″ gauge, for a double road, with a "six-foot" way, the formation is made up to a width of 30 feet, and dressed off from centre to edge at a slope of 1 in 30 (see Fig. 1, frontispiece).

Since it is far easier to lift than to lower a load, less ballast is spread as a foundation on the formation than will ultimately be required under the sleepers.

The materials used for ballast have been described in Article 2.

Sleepers should be well packed directly under the rail-seat, and to a distance of 10 to 18 inches on each side, according to the gauge; the middle and ends should be only loosely filled with ballast. The joint sleepers should first of all be packed, then the intermediate ones, and lastly the joint sleepers again before the road is boxed up. A great deal depends on good packing; a loose road causes rapid wear.

Gangmen, unless prevented, are much given to driving a big piece of stone or kunker under the sleeper, from which treatment the sleeper suffers considerably, while the apparent firmness of the packing is delusive.

One of the first conditions of a good road is to keep the joints straight and level.

The height-board or straight-edge used on the 5′ 6″ gauge is a plank, 6 feet long, about 8 inches deep, and fitted with feet at either end to steady it, when placed on edge, on the rails. The height of the sighting-boards—which are used to determine whether intermediate points are to be picked up or lowered—corresponds with the white line of the height-board or straight-edge.

The latter should not, as a rule, be placed further than 300 feet away from the lifting-point. The rails across which it is placed, and those at the lifting-point, should, first of all, be brought to exact level by means of the spirit-level. One sighting-board is placed by the lifter, and over this he sights the white line of the height-board with the intermediate sighting-board, which is placed on the joints and middles of all intervening rails, and indicates whether the line at each point is to be lifted or lowered. On curves the stepped cant-board is applied to the lower rail to carry the height-board on the level.

The joints are the important points; for example, when old clayey ballast cannot at once be entirely renewed, it should first be removed from under the guard sleepers and there replaced by clean stuff. In picking up slack joints, the ordinary crowbar will be found to be handy and quite suited to the purpose.

A new or lifted road should not be fully boxed for some days, in order that it may settle and be packed up, as required.

In boxing (Fig. 1, frontispiece), it is not usual, on the

London and North-Western Railway, to fill in the ballast above the top of the sleepers; on the Midland and Great Eastern Railways also, it is no higher between the rails, but in the six-foot way it is nearly flush with the rail, and on the outside it curves off from the top of the chair. In India we like, as a rule, to have the rails and fastenings bare; but, in a dry and hot climate, it is advisable to lay on wood sleepers a light top dressing of ballast to protect them from fire from ash droppings, and at least sufficient ballast should be spread beyond the ends of the sleepers to cover them freely, when the ballast takes its natural slope.

Boxing the ballast on the foot and side of the rail helps to make a silent road. Many engineers attach great importance to the boxing outside the rails, forming heavy banquettes. It is a mistake to suppose that the mere weight of the ballast is an unimportant factor; it is not easy, for example, to steady a road with a light cinder-ballast, and, with such a material, a full banquette is absolutely necessary.

Grips must, of course, be cut, and cross-drains put in between —say—every fourth or fifth sleeper (but that will depend upon the rain and soil), so that no water may be allowed to lie on the line or under the ballast.

In lifting a wood sleeper road, it should first be stripped of ballast to make it as light as possible, and thus prevent the spikes from drawing when the road is forced up with heavy levers. The rails, not the sleeper, should be held up with the lever, and both rails should be lifted together, the levers being held in place until the joints are firmly packed, the intermediate sleepers being then packed, and lastly the joints again beaten up. The old bed ought always to be broken up and renewed with fresh ballast. Four men should be put on to pack a sleeper, and they should beat the ballast under both sides equally.

A road must not be lifted more than three inches at a time, the elevation being made up, if necessary, by repeated lifts of not more than three inches. The lift should be made towards approaching trains on a double line, and from a lower to a higher level on a single track, the elevation being worked off at each end with an easy grade.

51.—Treatment of Metal Sleepers.

The trough-shaped steel sleeper is packed in very much the same way as the wood sleeper, i.e., the ballast is packed tightly under the rail seat, and to a distance of 10 or 15 inches on each side, the middle being loosely filled, and at least sufficient ballast spread beyond the ends to cover them, and keep the ballast filling from slipping out under the edges.

The steel keys should be driven with a light hammer and the ends split.

In renewing steel sleepers the old bed ought always to be dug up and renewed with fresh ballast. Steel sleepers newly laid require considerable attention until they have become firmly bedded.

A cast-iron pot sleeper put into the road as a renewal is apt to break, if packed up too much, and to secure an even bearing it is advisable to open out and repack one or two sleepers on each side. Tie-bars should be gauged beforehand, and keys and cotters driven with a light hammer. If one pot alone is to be put in, a hole may be dug, and the pot canted into place. Our pots frequently break in the key-seat; this can be detected by the key lying loose in the jaw. If, through bad packing, the bowl be broken, the fact will be evident from a ring of loose ballast over the rim of the pot. Care should be taken, however, to consolidate the filling, so that the adjacent pots may not be overweighted and broken.

When pots "blow," the best way to secure the packing is to open out the earth to the rim of the pot, pack small ballast under it with picks, fill in earth or sand from the top as usual with punners, and with the addition of a little water this will hold firm.

A clay packing will probably set hard and shrink during the hot weather, and should be broken up, or the pot may split.

The importance of good keying is obvious. Pot sleepers at joints often get out of square and tighten the gauge. This is due to neglect on the part of the keyman.

Not unfrequently the key is so carelessly driven that the rail is tilted too much inwards and the edge of the rail sheared off by the jaw.

The rail should be exactly fitted in its proper position, and the key, if firmly driven, then acts as a cushion as well as wedge.

Accumulation of rust and dust between the rail and chair-seat and slack keying are the chief causes of the under table of rails being dented. The breakage of pots may also be traced almost invariably to slack keying.

In lifting a pot road, all filling and ballast should be removed and replaced with fresh packing. When the rail is tilted too much inwards from careless keying, the lifting should be done by applying the crowbar from the inner side of the rail. Indeed the rails ought to be unkeyed, lifted from the chair-seat while the latter is scraped and cleaned, and the key carefully re-driven.

A gang of nine men and a mate might thoroughly lift, pack, and reballast a quarter of a furlong a day.

The points to be observed in packing the cast-iron D. O. sleepers have been alluded to in Article 27.

52.—Curves.

As previously explained, short rails have occasionally to be put in on the inner side of curves to correct the advance of the inner rail-joints. Joints gain a lead on the inside equal to $\frac{(R + G)\ C}{R}$ (where C = length of rail) and, when the inside rail leads 2 inches, it is shortened by 4 inches.

To determine the amount of slack gauge to be allowed on sharp curves, we might find what is the versed sine on a chord whose length is that of the maximum rigid wheel-base plus the distance beyond to the points where the wheel-flanges touch the inner edge of the outer rail. This would, perhaps, give us a satisfactory result with rigid six-wheelers, but the flanges have already a certain amount of play within the gauge, and the journals and axle-boxes will yield somewhat. The conditions are neither definite nor constant, but the formula usually adopted is—

$$v = \frac{3\,C^2}{2\,R} \text{ (approximately) } \ldots\ldots \text{ (1),}$$

in which we adopt the following values:—

C = actual maximum rigid wheel-base in feet,
R = radius of curve, also expressed in feet, and
v = versed sine in inches.

This approximate formula is derived from the exact formula $R = \frac{C^2}{8\,v} + \frac{v}{2}$ by neglecting the last term, and modifying the first so that v may be expressed in inches.

Thus, on the 5′ 6″ gauge, with a maximum rigid wheel-base of 16 feet, this would give us—

$$v = \frac{384}{R}.$$

Accordingly, on this assumption, the allowances for slack gauge might be as follows :

R	v
512 feet	$\frac{3}{4}$ inch
614 "	$\frac{5}{8}$ "
768 "	$\frac{1}{2}$ "
1024 "	$\frac{3}{8}$ "
1536 "	$\frac{1}{4}$ "

while curves of 1600 feet radius or more should be spiked or keyed to straight gauge.

Similarly on the metre gauge, with a maximum rigid wheel base of 10 feet, the formula

$$v = \frac{150}{R}$$

would give us slack gauge as follows:—

R	v
300 feet	$\frac{1}{2}$ inch
400 „	$\frac{3}{8}$ „
600 „	$\frac{1}{4}$ „

curves of more than 600 feet radius being laid to straight gauge.

Great caution should, however, be observed in the allowance of slack gauge on curves. For example, in a six-wheeler, the flanges may have as much as $\frac{1}{2}$-inch side-play between the rails; the journals and axle-boxes may account for $\frac{1}{4}$-inch more; the slack increases as the wheels wear; and the flanges of the middle wheels are frequently turned thinner than the others. With well-designed stock it may almost be said that widening of the gauge will generally be unnecessary.

Double- or bull-headed rails—especially if of steel, which is so much more elastic than iron—are adapted to ordinary curves with greater ease than flat-footed rails; and, if it is necessary to bend the latter, they should first be cautiously heated. The middle ordinates in inches may be calculated by a similar formula to the one above quoted:—

$$v = \frac{3\,C^2}{2\,R} \text{ (approximately)};$$

where C represents the length of the rail in feet. At the end of the book is given a table of middle ordinates for different lengths of rails and radii of curves.

Some platelayers "stagger" the joints with flat-footed rails on sharp curves, to prevent the sharp elbows which are so often seen when the joints are opposite.

The next matter to consider is the cant or super-elevation of the outer rail. Avoiding the unscientific term "centrifugal force" in this connection—for the tendency of the train is not to fly outwards from the centre, but to move in a straight path —it is clear that, to change the direction of its movement so as to follow a curve, it is necessary to introduce a new force, always acting at right angles to the straight line in which the train tends to move—in other words, a force normal to the curve. In doing this we are simply following Newton's first law of motion. The force of gravity is therefore induced to effect this change of direction by canting the permanent way, either entirely by lifting the outer rail, or partly by also lowering the inner rail. The cant should begin before the springing and finish beyond the end of the curve, the rise or fall increasing or decreasing at a grade of—say—1 in 600. In fact, the curve does not (or should not) end abruptly, but is gradually eased off into the straight, the curvature and cant diminishing together.

Let E = the required cant,
V = maximum velocity of trains,
R = radius of curve,
G = gauge,
g = accelerative effect of gravity,

Then

$$\frac{E\,g}{G} = \frac{V^2}{R}$$

$$\left.\begin{aligned} \therefore\quad E &= \frac{G\,V^2}{g\,R} \\ &= \frac{G\,V^2}{32 \cdot 2\,R} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (2)$$

Otherwise, the chord C may be determined, the versed sine of which on any curve will give the required cant. Substituting $\frac{C}{8\,E}$ for R in formula (2) we obtain

$$C = \tfrac{1}{2}\,V\,\sqrt{G} \text{ (approximately)}. \quad . \quad . \quad . \quad (2a)$$

It is convenient, however, to express E in inches, V in miles per hour, and G, C and R in feet. Adapted to these units, the formulæ are modified as follows:

$$\frac{E}{12} = \frac{G\,V^2}{32 \cdot 2\,R} \times \left(\frac{5280}{3600}\right)^2$$

$$\therefore\quad E = \frac{G\,V^2}{1 \cdot 25\,R} \text{ (approximately)}. \quad . \quad . \quad . \quad (2b)$$

$$C = \tfrac{1}{2} V \sqrt{G} \times \frac{5280}{3600}$$

$$\therefore \quad C = \tfrac{11}{15} V \sqrt{G} \text{ (approximately)}; \quad . \quad . \quad (2c)$$

and from these formulæ we deduce :—

$$\left.\begin{array}{ll}
(5'\ 6''\text{ gauge}) & E = \dfrac{4 \cdot 4091\ V^2}{R} \\
(5'\ 3''\text{ gauge}) & E = \dfrac{4 \cdot 2087\ V^2}{R} \\
(5'\ 0''\text{ gauge}) & E = \dfrac{4 \cdot 0083\ V^2}{R} \\
(4'\ 8\tfrac{1}{2}''\text{ gauge}) & E = \dfrac{3 \cdot 7744\ V^2}{R} \\
(3'\ 6''\text{ gauge}) & E = \dfrac{2 \cdot 8058\ V^2}{R} \\
(\text{metre gauge}) & E = \dfrac{2 \cdot 6302\ V^2}{R} \\
(3'\ 0''\text{ gauge}) & E = \dfrac{2 \cdot 4050\ V^2}{R}
\end{array}\right\} (2d); \qquad
\left.\begin{array}{l}
C = 1 \cdot 72\ V \\
C = 1 \cdot 68\ V \\
C = 1 \cdot 64\ V \\
C = 1 \cdot 59\ V \\
C = 1 \cdot 37\ V \\
C = 1 \cdot 33\ V \\
C = 1 \cdot 27\ V
\end{array}\right\} (2e).$$

C having been thus calculated, a string of this length is stretched from one point to another on the inside of the curve, station yards where speed is necessarily low, no cant may be required.

On sharp curves with flat-footed rails, check rails and a slower speed are preferable to too great a cant, since the tendency is to throw the weight of the train too much on the inner rail in the latter case and to draw the spikes. In England, flat-footed rails, on curves of 15 chains (990 feet) radius or less, must be held to gauge by iron or steel ties at suitable intervals; and, on curves of 10 chains (660 feet) radius or less, a check rail for the inner rail must be provided. In India, on our 5′ 6″ gauge, Sir Alex. Rendel would lay check rails on curves of 800 feet or less, on grades of 1 in 100.

A long and rigid wheel-base throws great strain on the fastenings on sharp curves. American "Railroad" men speak well of our permanent way, both in England and in India, but are critical about our rolling-stock. Uneasy running—they say—may as often be attributed to too great rigidity in our carriage-frames, where we adopt bogies, or to too short a wheel-base and too much overhang in our four-wheelers, or to weak buffer and bearing springs, or to loose coupling, as to defects in our permanent way.

53.—Laying Points and Crossings.

The more obtuse crossings, having an inclination of 1-in-5 or 1-in-6, are only used in temporary sidings, or sidings to which engines are admitted, except when such a crossing is laid with two curves of contrary flexure, and forms the junction between two split lines, as in Fig. 17. In this latter case, supposing the arrangement to be symmetrical, the radius of the diverging curves is equal to twice the radius of the curve which is put in for the same crossing off the straight, as in Fig. 16. Thus, on the 5′ 6″ gauge a 1-in-6 crossing forming the junction between two split lines (Fig. 17) would be as easy to run over as a 1-in-8½ crossing laid in for a siding leaving a straight main line (Fig. 16), the radius of the curves being 800 feet in either case.

Medium crossings, having an inclination of 1-in-7 to 1-in-10, are used for ordinary work in station yards.

The more acute crossings, from 1-in-10 to 1-in-12, are required for facing points on main line junctions and similar positions, where an easy curve is of more importance than economy of space. On the Highland Railway single line 1-in-16 crossings are used for facing points, and these are spread, so that the radius does not exceed 4835 feet, and one is scarcely conscious of running on a curve; the switches are 18 or 21 feet long. But, for ordinary purposes, on the 4′ 8½″ gauge, a 1-in-10 crossing is generally easy enough, the curve of the straight having a radius of about 950 feet.

The lead of a crossing is the distance measured on the straight, from the heel of the switch to the intersection of the gauge-lines on the crossing. It is generally calculated with reference to that portion of a *uniform* curve which is intercepted between the heel of the switch and the nose of the crossing.

It is by no means necessary, however, to have a uniform curve from heel to nose. If a longer than the correct lead be put in, the curve will be flatter at the heel but sharper at the nose—and this, of course, is the worst possible arrangement; the idea of some platelayers that a crossing can be improved by putting in a long lead is utterly absurd. If, on the other hand, a shorter lead be adopted, we shall have a sharper curve near the heel, but we may also have a piece of straight over the crossing itself; so that this is the best arrangement of all when a sufficiently acute crossing is chosen to admit of the curve being made somewhat sharper at the heel.

The most common arrangement is that shown in Fig. 2, where one line turns out with a curve from a straight track, and the manner of laying points and crossings in this way will now be explained.

First of all the straight line is spiked with its stock-rail and switch in position. The opposite stock-rail and switch can then be placed to exact gauge, and the heel-chair spiked down. The siding stock-rail should be bent in slightly, just beyond the toe of the switch. While the jim-crow is still applied to the rail, the chair at the toe of the switch, the one in front, and the next slide-chair behind, should be spiked to somewhat tight gauge, and afterwards the rest of the slide-chairs. The tightness of gauge near the toe of the switch will disappear when the first train has passed over the crossing.

Similarly, in putting in the crossing, the chair or lug of the crossing on the straight line side should first be spiked, and then those on the other side.

The gauge, says Mr. Barry, should generally be $\frac{1}{4}$ or $\frac{3}{8}$ of an inch tighter at the points and crossing them at other parts of the line, in order that the wheels may have less lateral play, and not strike the toe of the switch or the nose of the crossing. As a rule, we may advise that the gauge be a little tight in front of the points—in order to pull the train together for its approach and prevent oscillation—easy between the heel and the nose, and exact at the nose of the crossing and heel of the switch. It has previously been mentioned that sometimes (as in the Great Western Railway) the stock-rail is cranked so as to house a blunter switch-toe than usual.

The cant, obtainable only by lowering the off siding rail, should begin at the butt of the stock-rail, and (unless there is a piece of straight over the crossing) be continued right through. This advice—to allow cant at the crossing—is by no means orthodox, but will be justified by trial and experience. To get a cant here the off rail must be countersunk, and it will be difficult to obtain more than an inch, but even this will materially assist the wheels over the curve and prevent them from mounting the nose of the crossing.

It is obvious, however, that a cross-over road must be on one dead level, for there is no room to run out the opposite cants before they meet midway.

The check-rails should be placed well forward to protect the nose of the crossing, and not so far back as to make one think that their purpose was forgotten.

Too many long sleepers should not be used. Three or four will be required under the crossing and two at the end of the switches to carry the lever, and these should be of sound hard wood, such as teak or sâl. Beyond the crossing the short sleepers of each road should be so laid alternately that they may easily be packed together, and that the dividing roads may be independently adjustable. As stop indicators, we in India sometimes fix a whitewashed half-rounded sleeper in the middle way, to mark the fouling-point in shunting.

In all station yards spare point-rods, chairs, and switches should be kept ready for immediate renewals.

54.—Level Crossings.

To keep the wheel flange passages clear a check-rail is laid on the inside of each rail, and the space between should be cleared of dust and rubbish by the gateman, who ought also to water the crossing before a train is expected, to prevent dust from getting into the working parts of the engine. Sometimes, and with advantage, a check-rail is laid on both sides of the main rail.

of maintaining the permanent way will occasionally appear to be irregular and excessive. This cannot always be taken as a sign of imperfect maintenance on the part of the engineers and platelayers. It is more often due to starving the renewals when the revenues of the railway are low, and allowing the defects to accumulate until heavy special renewals are suddenly and imperatively needed.

The statistics of renewals during any one year are seldom significant taken by themselves. Moreover, the distinction between special and ordinary renewals is frequently fallacious: for the former may be, as explained above, an accumulation of renewals which should have been regularly carried out in the ordinary course of maintenance. One exception to the assimilation of special and ordinary renewals would be a replacement of a certain class of road by a more substantial one capable of bearing a heavier and faster traffic. This should be charged in part to Capital; the rule on Indian State Railways is to charge all the labour and an amount equal to the original cost of material to Revenue, the difference between the original cost of the discarded permanent way and the cost of the new material (if greater) being debited to Capital.

CHAPTER III.

POINTS AND CROSSINGS.

56.—Object of Points and Crossings.

It has already been explained that the use of points and crossings is to enable trains to pass from one pair of metals to another; that the switches are short tapering steel rails, one pressing against one stock-rail to divert the train from the original line, and the other drawn away from the other stock-rail to allow the train to pass on that side; and that the main line rail is crossed by means of a crossing (of cast steel, or built up of steel rails), the nose of the crossing being at the intersection of the gauge-lines of the crossing rails, which here diverge to form protecting wings.

57.—Definitions.

other words, the gap between those rails plus the breadth of the head of the rail.

Inclination number, or number (to put it shortly) of the crossing.—The cotangent of the angle of the crossing; it is measured by the distance from nose of crossing at which the perpendicular offset from one gauge-line of the crossing to the other is unity.

Curve-lead.—The distance from springing of curve to nose of crossing, measured along the straight.

Switch-lead.—The distance from springing of curve to heel of switch, measured along the straight.

Lead of crossing.—The distance from nose of crossing to heel of switch, measured along the straight. By one method of calculation it is equal to the curve-lead minus the switch-lead.

58.—Symbols.

G = gauge.
a = angle of crossing.
$I = \cot a$ = number of crossing.
l = length of switch.
d = clearance.
$\delta = \sin^{-1}\left(\frac{d}{l}\right)$ = angle of divergence of switch.
$i = \frac{l}{d}$ = inclination-number of the switch.
R, R_1, R_2 = radii of curves of intersecting rails.
L' = curve-lead.
l' = switch-lead.
L = lead of crossing.

59.—Two Methods of determining the Lead.

For the purpose of primary investigation the simplest case may be considered—that of a turnout from a straight line—but it will afterwards be seen that the application to cases where both lines are curved is easy.

In determining the lead by the first method, the curve is assumed to lie tangentially upon the gauge-line of the switch-rail, springing from it at the heel and crossing the inner straight rail at the proper angle. The curve is not referred in any way to the gauge-line of the outer rail. We do not take it for granted that a switch will be used which will suit a previously determined curve, but accept a certain switch, clearance, and crossing, and make the lead and curve suit those conditions.

By the second method the first step is to determine the radius of the curve which would lie tangentially upon the gauge-line of the outer straight rail and cross the inner straight rail at the proper angle. The curve-lead may then be found, and also the switch-lead, the latter covering that portion of the curve which (being intercepted between the heel of the switch and the theoretical springing-point on the gauge-line of the outer straight rail) is imaginary. The lead of the crossing is simply the difference between the curve-lead and the switch-lead.

Of these two methods, the first is more immediately suggested by what occurs in practice. If the lines were laid according to the second method there would be a kink at the heel unless the switch were of a certain length. Now, as a matter of convenience the same switch is often used for different crossings and cannot possibly be correct for more than one. The curve, therefore, requires generally a little adjustment to avoid a kink at the heel of the switch. This cannot occur when the first method is adopted, since the given switch is at once made a datum line from which the curve starts. As, however, it is convenient to have certain leads laid down for certain crossings, without reference to the length of the switch, the second method is usually followed, and the slight error due to using a switch whose length is not that of the tangent to the imaginary portion of the curve may practically be ignored.

60.—First Method. Lead of Crossing.

Referring to figure 1,

$$\delta = \sin^{-1}\left(\frac{d}{l}\right)$$

$$i = \frac{l}{d}$$

as defined.

Then,

$$\begin{aligned} \angle\,\mathrm{CED} &= \angle\,\mathrm{KCE} \\ &= \angle\,\mathrm{KCF} + \angle\,\mathrm{FCE} \\ &= \angle\,\mathrm{KCF} + \angle\,\mathrm{FEC} \\ &= a + \delta - \angle\,\mathrm{CED} \end{aligned}$$

$$\therefore\quad \angle\,\mathrm{CED} = \frac{a + \delta}{2}$$

Moreover,

$$\begin{aligned} \mathrm{L} &= \mathrm{DE} \\ &= \mathrm{CD} \cot \mathrm{CED} \end{aligned}$$

$$\therefore\ \mathrm{L} = (\mathrm{G} - d) \cot\left(\frac{a + \delta}{2}\right) \quad . \ . \ . \ . \ . \quad (3)$$

Hence,

$$\begin{aligned} \mathrm{L} &= (\mathrm{G} - d)\,\frac{\cot\frac{a}{2}\cot\frac{\delta}{2} - 1}{\cot\frac{a}{2} + \cot\frac{\delta}{2}} \\ &= (\mathrm{G} - d)\,\frac{4\,\mathrm{I}\,i - 1}{2\,(\mathrm{I} + i)} \text{ (approximately)} \end{aligned}$$

$$\left.\begin{aligned} \therefore\ \mathrm{L} &= 2\,(\mathrm{G} - d)\,\frac{\mathrm{I}\,i}{\mathrm{I} + i} \text{ (approximately)} \\ &= 2\,(\mathrm{G} - d)\,\frac{\mathrm{I}\,l}{\mathrm{I}\,d + l} \text{ (approximately)} \end{aligned}\right\} \ . \ (3a)$$

61.—First Method. Radius of Crossing.

Again, referring to figure 15,

$$C\,E = \frac{G - d}{\sin\left(\frac{a + \delta}{2}\right)}$$

But—

$$C\,E = 2\,R \sin\left(\frac{a - \delta}{2}\right)$$

$$\therefore\ R = \tfrac{1}{2}\,(G - d)\ \text{cosec}\left(\frac{a - \delta}{2}\right)\ \text{cosec}\left(\frac{a + \delta}{2}\right) \quad . \; . \; (4)$$

62. Second Method. Radius of Crossing.

Referring to figure 16,

$$R = \frac{G}{\text{versin}\ a} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; (5)$$

This will be a convenient formula if the crossing is described in terms of the angle, and that angle is simply expressed. As, however, R is found by dividing a small number by a *very* small number, the slightest roughness of approximation in the denominator may affect the result considerably. Hence, if the

From the last we obtain the following special approximate formulæ:—

$$\left.\begin{array}{lll}
\text{Gauge.} & & \\
5'\,6'' & \ldots & R = 11\ I^2 + 8\cdot25 \\
5'\,3' & \ldots & R = 10\cdot5\ I^2 + 7\cdot87 \\
5'\,0'' & \ldots & R = 10\ I^2 + 7\cdot5 \\
4'\,8\tfrac{1}{2}'' & \ldots & R = 9\cdot4166\ I^2 + 70\cdot6 \\
3'\,6'' & \ldots & R = 7\ I^2 + 5\cdot25 \\
\text{metre} & \ldots & R = 6\cdot5618\ I^2 + 4\cdot921 \\
3'\,0'' & \ldots & R = 6\ I^2 + 4\cdot5 \\
2'\,6'' & \ldots & R = 5\ I^2 + 3\cdot75
\end{array}\right\} \ldots \text{(5}b\text{)}$$

63.—Curve-lead.

Again referring to figure 16,

$$L' = R \sin a \ldots\ldots\ldots \text{(6)}$$

and, by easy transpositions,

$$\left.\begin{aligned} L' &= \frac{R}{\sqrt{(1 + I^2)}} \\ &= \frac{R}{I} \text{ (approximately)} \end{aligned}\right\} \ldots\ldots \text{(6}a\text{)}$$

or, in terms of G and I,

$$\left.\begin{aligned} L' &= G\,(I + \sqrt{1 + I^2}) \\ &\left.\begin{aligned} &= G\left(2\,I + \frac{1}{2\,I}\right) \\ &= 2\,G\,I \end{aligned}\right\} \text{ (approx.)} \end{aligned}\right\} \ldots\ldots \text{(7)}$$

or, again, in terms of G and a,

$$\left.\begin{aligned} L' &= G \cot \frac{a}{2} \\ &= \frac{G \sin a}{1 - \cos a} \end{aligned}\right\} \ldots\ldots\ldots\ldots \text{(7}a\text{)}$$

moreover,

$$2\,R - G : L' :: L' : G$$

$$\left.\begin{aligned} \therefore\ L' &= \sqrt{(2\,R - G)\,G} \\ &= \sqrt{2\,R\,G} \text{ (approx.)} \end{aligned}\right\} \ldots \text{(8)}$$

From the approximate formula 7—

$$L' = G\left(2\,I + \frac{1}{2\,I}\right)$$

we obtain the following special approximate formulæ:

$$\begin{array}{lll}
\text{Gauge.} & & \\
5'\,6'' & \ldots & L' = 11\,I + \dfrac{2\cdot75}{I} \\
5'\,3'' & \ldots & L' = 10\cdot5\,I + \dfrac{2\cdot625}{I} \\
5'\,0'' & \ldots & L' = 10\,I + \dfrac{2\cdot5}{I} \\
4'\,8\tfrac{1}{2}'' & \ldots & L' = 9\cdot4166\,I + \dfrac{2\cdot354}{I} \\
3'\,6'' & \ldots & L' = 7\,I + \dfrac{1\cdot75}{I} \\
\text{metre} & \ldots & L' = 6\cdot5618\,I + \dfrac{1\cdot64}{I} \\
3'\,0'' & \ldots & L' = 6\,I + \dfrac{1\cdot5}{I} \\
2'\,6'' & \ldots & L' = 5\,I + \dfrac{1\cdot25}{I}
\end{array}\left.\vphantom{\begin{array}{l}a\\a\\a\\a\\a\\a\\a\\a\\a\\a\\a\\a\\a\\a\\a\\a\end{array}}\right\} \quad \ldots (7b)$$

64.—Switch-lead.

will apply to the switch-lead; and, by working out the simultaneous equations between the practical extremes (1-in-5 and 1-in-16), we arrive at the following special approximate formulæ:—

$$
\left.\begin{array}{lcl}
\text{Gauge.} & & \\
5'\,6'' & \ldots\ldots & l' = 2{\cdot}7907\,\mathrm{I} + \dfrac{1{\cdot}0125}{\mathrm{I}} \\
5'\,3'' & \ldots\ldots & l' = 2{\cdot}7267\,\mathrm{I} + \dfrac{0{\cdot}985}{\mathrm{I}} \\
5'\,0'' & \ldots\ldots & l' = 2{\cdot}6609\,\mathrm{I} + \dfrac{0{\cdot}9635}{\mathrm{I}} \\
4'\,8\tfrac{1}{2}'' & \ldots\ldots & l' = 2{\cdot}6575\,\mathrm{I} + \dfrac{0{\cdot}964}{\mathrm{I}} \\
3'\,6'' & \ldots\ldots & l' = 2{\cdot}0917\,\mathrm{I} + \dfrac{0{\cdot}752}{\mathrm{I}} \\
\text{metre} & \ldots\ldots & l' = 1{\cdot}9908\,\mathrm{I} + \dfrac{0{\cdot}72}{\mathrm{I}} \\
3'\,0'' & \ldots\ldots & l' = 1{\cdot}872\,\mathrm{I} + \dfrac{0{\cdot}671}{\mathrm{I}} \\
2'\,6'' & \ldots\ldots & l' = 1{\cdot}5134\,\mathrm{I} + \dfrac{0{\cdot}54}{\mathrm{I}}
\end{array}\right\} \; . \quad (10a)
$$

65.—Second Method. Lead of Crossing.

To find the lead of the crossing we have merely to subtract the switch-lead from the curve-lead:

$$\mathrm{L} = \mathrm{L}' - l' \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (11)$$

66.—Approximate Formulæ for Leads.

The approximate formula for the curve-lead,

$$\mathrm{L}' = 2\,\mathrm{G}\,\mathrm{I},$$

gives us the well-known "platelayer's rule" for the lead:—"The lead is equal to twice the gauge multiplied by the number of the crossing." This rule, however, does not give the lead of the crossing but only the curve-lead from which the switch-lead has still to be deducted.

The following special approximate formulæ are sufficiently correct:

$$\left.\begin{array}{lll}
\text{Gauge.} & & \\
5'\ 6'' & \ldots & L = 8\cdot2093\,I + \dfrac{1\cdot7375}{I} \\
5'\ 3'' & \ldots & L = 7\cdot7733\,I + \dfrac{1\cdot64}{I} \\
5'\ 0'' & \ldots & L = 7\cdot3388\,I + \dfrac{1\cdot5197}{I} \\
4'\ 8\tfrac{1}{2}'' & \ldots & L = 6\cdot759\,I + \dfrac{1\cdot39}{I} \\
3'\ 6'' & \ldots & L = 4\cdot9083\,I + \dfrac{0\cdot998}{I} \\
\text{metre} & \ldots & L = 4\cdot5708\,I + \dfrac{0\cdot92}{I} \\
3'\ 0'' & \ldots & L = 4\cdot1281\,I + \dfrac{0\cdot812}{I} \\
2'\ 6'' & \ldots & L = 3\cdot4868\,I + \dfrac{0\cdot69}{I}
\end{array}\right\} \quad . \quad (12)$$

It need scarcely be observed that these have precisely and

67.—Curves of Contrary Flexure.

In figure 17,

$$\text{B D}^2 - \text{C D}^2 = \text{A B}^2 - \text{A C}^2$$

$$\therefore \text{B D} - \text{C D} = \frac{\text{A B}^2 - \text{A C}^2}{\text{B C}}$$

$$= \frac{R_1{}^2 - R_2{}^2}{R_1 + R_2 - G}.$$

Again,

$$\text{B D} = \tfrac{1}{2}(\text{B C} + \overline{\text{B D} - \text{C D}})$$

$$= \tfrac{1}{2}\left(R_1 + R_2 - G + \frac{R_1{}^2 - R_2{}^2}{R_1 + R_2 - G}\right).$$

But

$$\text{A D} = \sqrt{\text{A B}^2 - \text{B D}^2}$$

$$\therefore L' = \sqrt{R_1{}^2 - \tfrac{1}{4}\left(R_1 + R_2 - G + \frac{R_1{}^2 - R_2{}^2}{R_1 + R_2 - G}\right)^2} \quad (13)$$

An approximate formula which will be much more serviceable can, however, easily be found.

If s and $G - s$ be the cross-distances from the nose of the crossing to the lines tangential to the curves at springing

$$L' = \sqrt{2 R_1 s}; \text{ and also}$$

$$L' = \sqrt{2 R_2 (G - s)} \text{ (approximately)};$$

whence, by eliminating s,

$$L' = \sqrt{\frac{2 R_1 R_2 G}{R_1 + R_2}} \text{ (approximately)}. \quad . \quad . \quad . \quad . \quad (13a)$$

and, in the same way,

$$l' = \sqrt{\frac{2 R_1 R_2 d}{R_1 + R_2}} \text{ (approximately)}. \quad . \quad . \quad . \quad . \quad (14)$$

When the radii of the curves are equal, we obtain the following formulæ, the case being obviously the same as if we halved the gauge and doubled the inclination-number :—

$$R = \frac{G}{2 \text{ versin } \frac{a}{2}} \quad \ldots\ldots\ldots\ldots \quad (15)$$

$$\left.\begin{aligned} &= 4\,G\,I^2 + \tfrac{3}{4}\,G \text{ (very closely)} \\ &= 4\,G\,I^2 \text{ (approximately)} \end{aligned}\right\} \quad \ldots \quad (15a)$$

$$L' = R \sin \frac{a}{2} \quad \ldots\ldots\ldots\ldots \quad (16)$$

$$= \frac{G}{2} \cot \frac{a}{4} \quad \ldots\ldots\ldots\ldots \quad (17)$$

$$\left.\begin{aligned} &= G\,I + G\sqrt{\tfrac{1}{4} + I^2} \\ &\left.\begin{aligned} &= G\left(2\,I + \frac{1}{8\,I}\right) \\ &= 2\,G\,I \end{aligned}\right\} \text{(approx.)} \end{aligned}\right\} \quad \ldots \quad (17a)$$

$$= \sqrt{\left(R - \frac{G}{4}\right) G} \quad \ldots\ldots \quad (18)$$

$$= \sqrt{R\,G} \text{ (approximately)} \quad \ldots\ldots \quad (18a)$$

and, finally, by a process similar to that by which the case of curves of contrary flexure was determined,

$$L' = \sqrt{R_1{}^2 + \tfrac{1}{4}\left(R_1 - R_2 - G + \frac{R_1{}^2 - R_2{}^2}{R_1 - R_2 - G}\right)^2} \quad (21)$$

Again, if *s* and G + *s* be the cross-distances from the nose of the crossing to the lines tangential to the curves at springing,

$$L' = \sqrt{\frac{2\,R_1\,R_2\,G}{R_1 - R_2}} \text{ (approximately) . . } (21a)$$

$$l' = \sqrt{\frac{2\,R_1\,R_2\,d}{R_1 - R_2}} \text{ (approximately) . . . } (22)$$

69.—Lead of Crossing Constant.

The formulæ for leads, thus obtained, in the case of curves of similar or contrary flexure are, however, of theoretical rather than practical interest.

Once having found the crossing which will suit a turnout from a straight line or a turnout from another curve of similar or contrary flexure, the lead as worked out by the formulæ applicable to each case, will practically be the same.

Thus, on the 5′ 6″ gauge, whether we put in a 7° 45′ crossing for two curves of contrary flexure, their radii being 1200 feet, or for a turnout from a straight line with a curve of 600 feet, the lead will be 60′ 7″ in either case.

This simplifies matters greatly. We have merely to find what crossing is suitable, and to determine the lead for the simplest case—that of a turnout from a straight line. Then this lead, provided the crossing be suitable, will be the same for that crossing, whatever the arrangement may be.

It is also to be remarked that, when the radii of two curves of contrary flexures are equal, each is very nearly equal to twice the radius of the crossing, that is, twice the radius of the curve of a turnout from a straight line.

70.—To Determine the Crossing.

1. Turnout with a curve of given radius from a straight line (Fig. 16).

In this case we need only express formula (5a) in another form:—

$$\left.\begin{aligned} I &= \frac{R - G}{\sqrt{(2R - G)G}} \\ &= \sqrt{\frac{R}{2G}} \text{ (approximately,} \end{aligned}\right\} \quad \ldots\ldots \quad (23)$$

while formula 5 becomes

$$\cos a = \frac{R - G}{R} \quad \ldots\ldots\ldots\ldots\ldots \quad (23a)$$

by which the angle of crossing may be determined.

2. Curves of contrary flexure (Fig. 17).

$$\sin^2\left(\frac{a}{2}\right) = \cos\left(\frac{180^\circ - a_1 - a_2}{2}\right)$$

$$= \frac{s\,(s - a)}{}\,,$$

or if—instead of having the radii given, to determine the required crossing—we have the crossing and one radius given, to determine the other,—

$$R_2 = \frac{\left(R_1 - \frac{G}{2}\right)\frac{G}{2}}{R_1 \sin^2\left(\frac{a}{2}\right) - \frac{G}{2}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (24a)$$

Again I, or cot a, is very nearly equal to ½ cosec $\left(\frac{a}{2}\right)$ when the angle is small, and

$$\tfrac{1}{2} \operatorname{cosec}\left(\frac{a}{2}\right) = \tfrac{1}{2}\sqrt{\frac{R_1 R_2}{\left(R_1 + R_2 - \frac{G}{2}\right)\frac{G}{2}}}\,.$$

$$\therefore\; I = \sqrt{\frac{R_1 R_2}{2\,(R_1 + R_2)\,G}} \text{ (approximately)} \quad . \; . \; . \quad (24b)$$

and, when the radii are equal,

$$\left.\begin{aligned} \sin^2\left(\frac{a}{2}\right) &= \frac{4\,R\,G - G^2}{4\,R^2} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \\ I &= \sqrt{\frac{R}{4\,G}} \text{ (approximately)} \quad . \; . \; . \end{aligned}\right\} \quad (25)$$

3. Curves of similar flexure (Fig. 18).—In this case—

$$\sin^2\left(\frac{a}{2}\right) = \frac{(s-b)(s-c)}{b\,c}$$

$$\therefore\; \sin^2\left(\frac{a}{2}\right) = \frac{\left(R_1 - R_2 + \frac{G}{2}\right)\frac{G}{2}}{R_1 R_2} \quad . \; . \; . \; . \; . \; . \; . \quad (26)$$

$$R_2 = \frac{\left(R_1 + \frac{G}{2}\right)\frac{G}{2}}{R_1 \sin^2\left(\frac{a}{2}\right) + \frac{G}{2}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (26a)$$

$$I = \sqrt{\frac{R_1 R_2}{2\,(R_1 - R_2)\,G}} \text{ (approximately)}. \quad (26b)$$

In the above approximate formulæ—

$$I = \sqrt{\frac{R}{2\,G}}$$

$$I = \sqrt{\frac{R_1\,R_2}{2\,(R_1 + R_2)\,G}}$$

$$I = \sqrt{\frac{R_1\,R_2}{2\,(R_1 - R_2)\,G}},$$

the following values of $\frac{1}{\sqrt{2\,G}}$ may be inserted :—

Gauge.	
5′ 6″	0·301515
5′ 3″	0·308607
5′ 0″	0·316228
4′ 8½″	0·325876
3′ 6″	0·377964
metre	0·390381
3′ 0″	0·408248
2′ 6″	0·447214

71.—Modification of the Lead in certain cases.

The inclination of a crossing is defined by such short lines for curves of contrary flexure; and

$$L = K\sqrt{\frac{R_1 R_2}{R_1 - R_2}} \text{ (approximately)}. \quad (29)$$

for curves of similar flexure; where K has the following values:—

Gauge.	
5′ 6″	2·471
5′ 3″	2·395
5′ 0″	2·317
4′ 8½″	2·199
3′ 6″	1·852
metre	1·781
3′ 0″	1·682
2′ 6″	1·557

This concession, however, is no argument for indifference to accuracy in calculation. In practice we may find it convenient to depart from the correct dimensions, but we ought to know exactly to what extent we are doing so.

Some platelayers have an idea that they can make a crossing easier by lengthening the lead. This is absurd. They simply flatten the curve near the switch, and sharpen the curve near the crossing, i. e. at the very worst place.

In fact, if the curve be easy, it may be advisable to shorten the lead; for although, in this case, the curve would have to be sharper towards the switch, we might be able to put in a piece of straight at the crossing, which would be an improvement.

So that we may say generally that the best arrangement is when an easy or acute-angled crossing is put in with a short lead (which may easily be calculated for any desired smaller radius of curve), and with a piece of straight over the crossing.

72.—Turnouts and Crossovers.

A turnout from one line to another (Figs. 19 and 21) is made by means of a pair of switches, a crossing, and a reverse curve running into the direction of the second line, with or without an intermediate portion of straight line.

When a turnout enters the branch-line by means of a second crossing, and a second pair of switches, it becomes a crossover (Figs. 20 and 22).

The whole length of a turnout, therefore, is made up of

(*a*) Lead of crossing (L),
(*b*) Intermediate portion (S), straight or curved,
(*c*) Curve-lead (L′);

while that of a crossover is made up of

(*a*) Lead of crossing (L),
(*b*) Intermediate portion (S), straight or curved,
(*c*) Lead of crossing (L).

1. Turnouts and crossovers, the intermediate portion being straight.

Here (Figs. 19 and 20) we have

$$\left.\begin{aligned} S &= \{D - G\,(1 + \sec\alpha)\}\cot\alpha \\ &= D\,I - G\,(1 + \sqrt{1 + I^2}) \\ &= D\,I - L' \\ &= (D - 2\,G)\,I \text{ (approximately)} \end{aligned}\right\} \quad \ldots\ldots \quad (30)$$

A platelayer may occasionally have to put in a crossover with crossings of different angles, and such a case may be dealt with here.

Let α be the angle of the acuter crossing, the inclination of which is 1-in-A; β, the angle of the other, a 1-in-B; D = distance between roads, centre to centre; x = offset from gauge-line of outer rail, at the point where the curve, continued beyond the first crossing, touches the inclination of the other crossing; M = length of the succeeding straight portion of the crossover; R_1 and R_2 = radii of crossings; and S = total length from nose to nose of crossings.

Referring to Fig. 24,

$$S = L'_3 - L'_1 + M.$$

But,

$$L'_3 = R_1 \sin \beta = \frac{G \sin \beta}{1 - \cos \alpha}.$$

Again,

$$L'_3 = x \cot \frac{\beta}{2} = \frac{x \sin \beta}{1 - \cos \beta}.$$

Therefore,

$$\frac{x \sin \beta}{1 - \cos \beta} = \frac{G \sin \beta}{1 - \cos \alpha}.$$

$$x = \frac{G\,(1 - \cos \beta)}{1 - \cos \alpha}.$$

Also,

$$M = (D - x - G \sec \beta) \cot B.$$

$$\therefore\ M = D \cot \beta - G \operatorname{cosec} \beta - \frac{G \cot \beta\,(1 - \cos \beta)}{1 - \cos \alpha}.$$

Moreover,

$$L'_1 = R_1 \sin \alpha = \frac{G \sin \alpha}{1 - \cos \alpha}.$$

Therefore,

$$\left.\begin{aligned}
S &= \frac{G\,(\sin \beta - \sin \alpha)}{1 - \cos \alpha} + D \cot \beta - G \operatorname{cosec} \beta \\
&\qquad - \frac{G \cot \beta\,(1 - \cos \beta)}{1 - \cos \alpha} \\
&= G\,(1 + A^2 + A\sqrt{1 + A^2}) \left\{ \frac{1}{\sqrt{(1 + B^2)}} \right. \\
&\qquad \left. - \frac{1}{\sqrt{(1 + A^2)}} - \frac{B}{1 + B^2 + B\sqrt{(1 + B^2)}} \right\} \\
&\qquad + D B - G\sqrt{(1 + B^2)} \\
&= 2\,G\,A^2 \left(\frac{1}{2\,B} - \frac{1}{A}\right) + B\,(D - G)\ \text{(approximately)}
\end{aligned}\right\} \tag{30a}$$

Thus, on the 5′ 6″ gauge, if we have to put in a crossover between roads 20 feet apart, centre to centre, with a 1-in-10 crossing, and a 1-in-7 crossing:—

$$S = (5\tfrac{1}{2} \times 201 \cdot 5)\left(\frac{1}{7 \cdot 07} - \frac{1}{10 \cdot 05} - \frac{7}{99 \cdot 49}\right) + 140 - 38 \cdot 88$$

$$= 140 - 69 \cdot 91$$

$$= 70 \cdot 09.$$

Or, using the approximate formula,

$$S = (5\tfrac{1}{2} \times 200)\left(\frac{1}{14} - \frac{1}{10}\right) + 140 - 38 \cdot 5$$

$$= 140 - 69 \cdot 9$$

$$= 70 \cdot 1.$$

When, in formulæ (30a), we put $B = A$, or $\beta = \alpha$, these at once simplify into the original formulæ (30).

2. Turnouts and crossovers, the intermediate portion being curved (Figs. 21 and 22).

The curve is continuous and reverse, the radius R in the following formula being that of the crossing rail:—

Referring to figure 25,

$$\left.\begin{aligned}
S &= \sqrt{2\,D\,(R_1 + R_2 - G) - D^2} - (L'_1 + L'_2) \\
&= \sqrt{2\,D\,G\,\{1 + A^2 + B^2 + A\,\sqrt{(1 + A^2)} + B\,\sqrt{(1 + B^2)}\} - D^2} \\
&\qquad - G\,(A + B + \sqrt{1 + A^2} + \sqrt{1 + B^2}) \\
&= \sqrt{2\,D\,G\left(\frac{1}{1 - \cos\alpha} + \frac{1}{1 - \cos\beta} - 1\right) - D_2} \\
&\qquad - G\left(\cot\frac{\alpha}{2} + \cot\frac{\beta}{2}\right), \\
&\text{and, substituting in terms of } R = 2\,G\,I^2 + 1\tfrac{1}{2}\,G, \\
&= \sqrt{4\,D\,G\,(1 + A^2 + B^2) - D^2} - 2\,G\,(A + B), \\
&\qquad \text{approximately.}
\end{aligned}\right\} \quad . \ (31a)$$

Thus, on the 5′ 6″ gauge, if the main lines be 20 feet apart, centre to centre, and the crossings be 1 in 10 and 1 in 7, the exact formula will give us 68·46, and the approximate formula 69 feet, as the length of S, the distance from nose to nose of crossings.

If we put B = A, or $\beta = \alpha$, formulæ (31*a*) are simplified into the original formulæ (31).

The case of a crossover between two parallel curved roads may also be briefly indicated here.

Referring to Fig. 23, it is seen at once that it depends on the solution of a triangle of which the three sides are known. The curves in the figure coincide with the centre lines of the roads.

To find γ, the angle at the centre, we may use the formula:

$$\cos\gamma = \frac{a^2 + b^2 - c^2}{2\,a\,b}$$

where

$$\begin{aligned}
a &= R + r_2 - D \\
b &= R - r_1 \\
c &= r_1 + r_2.
\end{aligned}$$

Thus, on the 5′ 6″ gauge, with a 1-in-10 and a 1-in-7 crossing, the main lines being 20 feet apart, centre to centre, let us assume that R = 4000.

With these data, we shall find that $r_1 = 797 \cdot 40$ and $r_2 = 620 \cdot 75$.

Hence we successively obtain,

$$\begin{aligned} \gamma &= 3^\circ\ 32'\ 45'' \\ c &= 247 \cdot 72 \\ s &= 247 \cdot 72 - (110 \cdot 27 + 77 \cdot 39) \\ &= 60 \cdot 06 \text{ feet, measured along the outer rail.} \end{aligned}$$

73.—Gathering Lines.

In figure 26, let

S = distance from nose to nose of crossings, measured in the direction of the parallel roads.
V = the same, measured in the direction of the gathering line.
D = distance between parallel roads, centre to centre.
α, A = angle and inclination-number of crossings.
θ, X = angle and cotangent of angle which the gathering line makes with the parallel roads.

Then,

$$\left.\begin{aligned} Y &= \frac{T \sin a}{\sin \theta} \\ &= T \times \frac{\sqrt{1 + X^2}}{\sqrt{1 + A^2}} \end{aligned}\right\} \quad \ldots\ldots\ldots (35)$$

$$\left.\begin{aligned} Z &= \frac{T \sin (\theta - a)}{\sin \theta} \\ &= T \times \frac{A - X}{\sqrt{1 + A^2}} \end{aligned}\right\} \quad \ldots\ldots\ldots (36)$$

When θ = "the limiting angle," i. e. the greatest angle at which the gathering line can be run across the parallel lines, each crossing fits against the butt of the next stock-rail; no piece is put in, and no room is lost between them; if the gathering line be indefinitely extended, the tracks being equidistant, each crossing in succession will occupy a similar position; and there will be no fear of being jammed.

The examination of this case will be of assistance where economy of space has to be studied in laying out a yard, and will prevent the designer, perhaps, from proposing impossible arrangements in the plan.

To find θ, the limiting angle, V must be equal to the sum of the length of the crossing, the lead, the switch, and of that part of the stock-rail which lies beyond the toe of the switch and butts against the crossing, while D must be equal to the least distance between roads.

Thus, with 7° 45′ crossings on the metre gauge, $V = 4' + 33' \, 9'' + 15' \, 1'' = 52' \, 10''$; $D = 12$; $\sin \theta = \frac{12}{52 \cdot 8333}$; and θ, the limiting angle, $= 13° \, 7' \, 41''$.

When the gathering line runs across the parallel lines at the angle of the crossings as in Fig. 27, $\theta = a$, and

$$\left.\begin{aligned} V &= D \operatorname{cosec} a \\ &= D \sqrt{1 + A^2} \end{aligned}\right\} \quad \ldots\ldots\ldots (37)$$

$$\left.\begin{aligned} S &= D \cot a \\ &= D\,A \end{aligned}\right\} \quad \ldots\ldots\ldots (38)$$

When two roads cross each other, we have a diamond crossing. According to the requirements of the Board of Trade, diamond crossings ought not, as a rule, to be flatter than 1-in-8. If possible, they should be limited to 1-in-6.

In this case, we may, if necessary, put in compounds within the crossings as in Figs. 28*a* and 28*b*, where

$$\left.\begin{aligned} T &= G \operatorname{cosec} a \\ &= G \sqrt{1 + A^2} \\ &= G A \text{ (approx.)} \end{aligned}\right\} \quad . \ (39)$$

$$\left.\begin{aligned} R &= T \cot \frac{a}{2} \\ &= T \left(\sqrt{1 + A^2} + A\right) \\ &= G \left\{1 + A^2 + A \sqrt{1 + A^2}\right\} \\ &= 2 G A^2 \text{ (approx.)} \end{aligned}\right\} \quad . \ (40)$$

$$\left.\begin{aligned} Y &= R \left(\sec \frac{a}{2} - 1\right) \\ &= R \left(\sqrt{\frac{2\sqrt{1 + A^2}}{\sqrt{1 + A^2} + A}} - 1\right) \\ &= \frac{T^2}{2 R} \text{ (approx.)} \\ &= \frac{G}{4} \text{ (approx.)} \end{aligned}\right\} \quad . \ (41)$$

line. In this case, the curve-lead of the intermediate crossing, α, is calculated in the usual way, the radii of the outer crossings, β_1 and β_2. being known, but the switch-lead must be calculated for a double clearance, 2 *d*;

$$\left.\begin{aligned} L' &= \sqrt{\frac{2 R_1 R_2 G}{R_1 + R_2}} \\ l' &= \sqrt{\frac{4 R_1 R_2 d}{R_1 + R_2}} \\ L &= L' - l' \end{aligned}\right\} \text{(approx.)} \quad \ldots \quad (43)$$

When the outer crossings—as will usually be the case—are of the same number, $R = R_1 = R_2$, and these formulæ become

$$\left.\begin{aligned} L' &= \sqrt{R G} \\ l' &= \sqrt{2 R d} \\ L &= L' - l' \end{aligned}\right\} \text{(approx.)} \quad \ldots \quad (43a)$$

On the 5′ 6″ gauge we may have such an arrangement with two 1-in-8½ crossings and a 1-in-6, the radius being 800 feet; or with two 7° 45′ crossings and a 10° 45′ crossing, the radius being 600 feet. On the metre gauge, two 1-in-9½ crossings and a 1-in-6¾ will serve, the radius being 600 feet; or two 7° 45′ crossings and an 11° crossing, the radius being 360 feet. On the 4′ 8½″ gauge, two 1-in-7 crossings may be used with a 1-in-5, the radius being about 470 feet; or two 1-in-8 crossings with a 1-in-5½, the radius being 600 feet; or two 1-in-10 crossings with a 1-in-7, the radius being 950 feet.

In Fig. 31, two lines of different radii turn out on the same side of the straight line.

Here we may choose an intermediate crossing with the most obtuse angle, *a*, and a curve of the shortest radius permissible.

The corresponding curve-lead is calculated in the usual manner, but the switch-lead for a double clearance, 2 *d*:

$$\left.\begin{aligned} L' &= \sqrt{2 R G} \\ l' &= 2 \sqrt{R d} \\ L &= L' - l' \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (44)$$

The distance, K, between the springing of the curve of line No. 2 and that of line No. 3, is equal to the difference in length between the switch-lead of the former calculated for the ordinary clearance, *d*, and the switch-lead of the latter calculated for a double-clearance.

The angles, α and β, of the crossings of lines No. 2 and No. 3 over line No. 1 having been selected, and the distance K determined, the angle β_2 and other details of the crossing between lines No. 2 and No. 3 may be found in a way similar to that indicated below for the arrangement shown in Fig. 30, which is a substitute for three-throws and will now be briefly referred to.

Some engineers dislike three-throws and prefer to put one set of switches behind the other as in Fig. 30. In this case, the curve-lead may be determined from two simultaneous approximate equations.

$$L' = \sqrt{2R(G - s)}$$
$$L' - K = \sqrt{2Rs}$$

where R is the radius of curve of both the outer crossings, their angle being β, while K is equal to the measured distance from heel to heel. Hence, eliminating s, we obtain

75.—Triangles.

At temporary termini, where turntables will not ultimately be required, it is usual to put in triangles for reversing engines.

One arrangement of triangle is that shown in Fig. 32. So far as the purpose of turning the engine is concerned, the third side A B is not necessary, but it generally forms part of an already existing through siding.

The distance from the theoretical springing of the curve of crossing A to that of crossing B is obviously equal to $2\,R - G$, where R is the radius of the crossing rails: and the perpendicular distance from the theoretical springing of crossing C to the centre of the track A B is equal to $R - \frac{G}{2}$.

Hence, if $S =$ distance between the crossings A and B, and $L'_1 =$ curve-lead of each of those crossings,

$$S = 2\,R - G - 2\,L'_1 \quad . \; . \; . \; . \; . \; . \; (47)$$

and, if $D =$ distance of crossing C from the centre-line of the track A B, and L'_2 the curve lead,

$$D = R - \frac{G}{2} - L'_2 \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (48)$$

The crossings A and B have the same angle, while that of C is chosen to suit the particular radius.

Thus, on the 5′ 6″ gauge, 1-in-8½ crossings may be placed at A and B, and a 1 in 6 at C. Moreover

$$R = 802{\cdot}99;\; S = 1{,}412'10'';\; \text{and } D = 733'10''.$$

If a triangle be laid out as shown in figure 33, it occupies the least possible space for a given limited radius. The arrangement is equiangular, each crossing having the same angle.

Let R = radius of the crossing rails; S = distance between the crossings; and L′ = curve-lead of each of the crossings.

Then, evidently,

$$\left.\begin{aligned} S &= R - L'\sqrt{3} \\ &= R - 1{\cdot}732\,L' \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots \quad (49)$$

Thus, on the 5 6″ gauge, with a 1-in-6 crossing at A, B and C R = 800; L′ = 66′ 5″; S = 685.

76.—Crossing more than one line; Diamond Crossings.

Referring to Fig. 34, in order to obtain the curve-leads or distances from the theoretical springing of the curve on the first line, we must substitute for G and R in the formula for curve-lead,

$$L' = \sqrt{(2R - G)\,G},$$

the following:—

for No. 1 crossing .. .. G and R,

To determine the crossings:

$$\left.\begin{array}{ll}
\sin a_1 = \dfrac{L'_1}{R}; & I = \dfrac{L'^2 - G^2}{2\,L'G} \\
\sin a_2 = \dfrac{L'_2}{R - G}; & I = \dfrac{L'^2 - (D - G)^2}{2\,L'(D - G)} \\
\sin a_3 = \dfrac{L'_3}{R}; & I = \dfrac{L'^2 - (D + G)^2}{2\,L'(D + G)} \\
\sin a_4 = \dfrac{L'_4}{R - G}; & I = \dfrac{L'^2 - (2\,D - G)^2}{2\,L'(2\,D - G)} \\
\sin a_5 = \dfrac{L'_5}{R}; & I = \dfrac{L'^2 - (2\,D + G)^2}{2\,L'(2\,D + G)}
\end{array}\right\} \quad . \; . \; . \; (51)$$

The case of crossings on mixed gauges is similar, and need not be more particularly described.

77.—Tables.

These include details of points and crossings, turnouts and crossovers, cant on curves, and middle ordinates of rails on curves. The tables for points and crossings have now been worked out for the intermediate numbers—5½, 6½, 7½, &c.; they extend up to 1-in-16 crossings, such being laid on the Highland and other railways; and they cover the following gauges, which are stated (in Barry's 'Railway Appliances') to be in use in the following countries:—

5′ 6″—India, Spain, Portugal, Brazil, Argentine Republic and Chili.

5′ 3″—Ireland, Victoria, South Australia, New Zealand and Brazil.

5′ 0″—Russia.

4′ 8½″—Great Britain, Canada, Nova Scotia, New South Wales, France, North Germany, Holland, Belgium, Austria, Hungary, Turkey, Switzerland, Italy, Norway, Sweden, Denmark, Egypt, United States, Brazil, Uruguay and Peru.

3′ 6″—Queensland, Tasmania, Cape Colonies, Norway, Egypt, Brazil and Japan.

Metre—India, Brazil and Argentine Republic.

3′ 0″—United States.

2′ 6″—No countries are named, but we have in India the Kaunia-Dharlla, the Cooch Behar State, the Gaekwar's Dabhoi, the Morvi and other railways laid to this gauge.

The 5′ 6″ gauge has, perhaps, by this time disappeared in Canada, Nova Scotia and the United States. France and Switzerland have lines on the metre gauge; and the 3′ 0″ gauge has recently been introduced in Ireland.

The table—common to all gauges—of numbers and angles of crossings, and of factors applicable to the formulæ, will enable the reader to trace and check the calculations on which the following tables are based.

The graphic diagram (Fig. 37) on which the radius of curve, the curve-lead, switch-lead, and lead of crossing may be measured on the vertical ordinates for any inclination-number from 5 to 12, is adapted to six of the above-named gauges by the application of the proper vertical scale. Although the scale is a small one, the measurements will probably be accurate enough for general use, but the reader may easily plot a larger diagram for any particular gauge from the tables.

The tables giving the cant for different curves and maximum speeds for the 5′ 6″, 5′ 3″, 5′ 0″, 4′ 8½″, 3′ 6″, metre, and 3′ 0″ gauges, were calculated to the 32nd and 64th part of an inch, but have been reduced to differences of an eighth only for practical purposes.

Tables of middle ordinates of rails on curves are frequently given in decimals of a foot or an inch; it appears to be sufficient and more practical to work out the ordinates for round number radii of comparatively sharp curves, and to express them in vulgar fractions and to the nearest 32nd part of an inch.

CHAPTER IV.

SIMPLE RULES.

78.—To Set out a Curve by Offsets.

Rule.—To find O, the full offset for a chord of one chain of 66 feet, divide 4356 by R, the radius; for a chord of one chain of 100 feet, divide 10,000 by R (Fig. 35).

Formula.—

$$\left.\begin{aligned} C &= \frac{4356}{R} \text{ for 66-foot chords} \\ &= \frac{10,000}{R} \text{ for 100-foot chords} \end{aligned}\right\} \quad \ldots\ldots \quad (52)$$

Proof.—By similar triangles, in Fig. 35,

$$\frac{O}{C} = \frac{C}{R},$$

From here, in line with the tangent and second pegs, measure 100 feet and place a flag. Then shift the chain until the leader's end is at a distance equal to the offset O from the flag, while the follower's end is still held at the second peg. Drive a peg at the leader's end of the chain. This will be the third point on the curve.

The fourth and succeeding points may be found in the same way as the third, until the end of the curve is reached.

Here the direction of the tangent is determined by laying off the half-offset, $\frac{O}{2}$, instead of the full offset, O.

Example.—Let $R = 1273 \cdot 2$, and $C = 1000$. Then

$$\begin{aligned} O &= \frac{10,000}{1273 \cdot 2} \\ &= 8 \cdot 1449, \\ \therefore \quad O &= 8' \, 1\tfrac{3}{4}''. \end{aligned}$$

79.—To Set out a Diversion from a Straight Line.

Rule.—To find L, the length of each half of the diversion (Fig. 36), add together the square (S^2) of the straight portion between the reverse curves and the product ($4 \, R \, D$) of four times the radius into the maximum distance of the diversion from the main line; subtract the square (D^2) of the maximum distance; and take the square root of the result.

To find the tangent (T), divide the product ($R \, D$) of the radius into the maximum distance by the sum ($L + S$) of the half of the diversion and the length of straight between the reverse curves.

Formulæ.—

$$L - \sqrt{S^2 + 4 \, R \, D - D^2} \quad . \; . \; . \; . \; . \; . \quad (53)$$

$$T = \frac{R \, D}{L + S} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (54)$$

Proof.—By similar triangles in Fig. 36,

$$\frac{T}{R} = \frac{R}{L + S},$$

$$\therefore \quad T = \frac{R\,D}{L + S}.$$

Again,

$$L = 2\,T + \sqrt{(2\,T + S)^2 - D^2},$$

$$\therefore \quad (L - 2\,T)^2 = (2\,T + S)^2 - D^2$$

$$\therefore \quad L^2 = 4\,T\,(L + S) + S^2 - D^2$$

$$\therefore \quad L^2 = \frac{4\,R\,D}{L + S}(L + S) + S^2 - D^2$$

$$\therefore \quad L = \sqrt{S^2 + 4\,R\,D - D^2}.$$

Directions.—From the middle point of the line, which is to be diverted, set off the maximum offset D. From the middle point of the diversion thus determined, measure parallel to the main line and in both directions the tangent lengths T. This fixes on each side one extremity of the common tangent lines.

From the middle point of the line, which is to be diverted, as shown in the figure, to avoid having to work off and resume the cant on the curves.

Example.—Let R = 1000, S = 100, and D = 50. Then

$$L = \sqrt{100^2 + (4 \times 1000 \times 50) - 50^2}$$

$$\therefore \quad L = 455\tfrac{1}{2}, \text{ and the whole length} = 911 \text{ feet.}$$

Also

$$T = \frac{1000 \times 50}{455\frac{1}{2} + 100}$$

$$\therefore \quad T = 90 \text{ feet.}$$

80.—To find the Radius of a Curve.

Rule.—Stretch a string 100 feet long upon the inside edge of the curved rails, and measure with a foot-rule the versine or distance from the middle of the string to the rail. Then the radius R is very nearly equal to 15,000 divided by v, the versine expressed in inches.

Formula.—

$$R = \frac{15{,}000}{v} \quad \ldots\ldots\ldots \quad (1a)$$

where v = versine in inches.

Example.—Let v = 10 inches. Then

$$R = \frac{15{,}000}{10}$$

$$\therefore \quad R = 1500 \text{ feet.}$$

81—To find the Cant Required on a Curve.

Rule.—Stretch a string of a certain length, according to the gauge and maximum speeds of trains, upon the inside of the curve. Then the versine is equal to the required cant.

Formulæ.—Where V = maximum speed in miles per hour, the following formulæ may be applied for each gauge, to find C the length of string to be used:—

$$\begin{array}{l}\text{Gauge.}\\ \left.\begin{array}{lcl} 5'\,6'' & \ldots\ \ldots & C = 1\tfrac{3}{4}\,V \\ 5'\,3'' & \ldots\ \ldots & C = 1\tfrac{2}{3}\,V \\ 5'\,0'' & \ldots\ \ldots & C = 1\tfrac{5}{8}\,V \\ 4'\,8\tfrac{1}{2}'' & \ldots\ \ldots & C = 1\tfrac{3}{5}\,V \\ 3'\,6'' & \ldots\ \ldots & C = 1\tfrac{3}{8}\,V \\ \text{metre} & \ldots\ \ldots & C = 1\tfrac{1}{3}\,V \\ 3'\,0'' & \ldots\ \ldots & C = 1\tfrac{1}{4}\,V \end{array}\right\}\end{array} \quad \ldots\ldots\ldots \quad (2f)$$

Example.—On the metre gauge, let $V = 30$ miles per hour. Then

$$C = 1\tfrac{1}{3} \times 30$$
$$\therefore\ C = 40 \text{ feet.}$$

If, therefore, a string 40 feet long be stretched along a curve whose radius is 1000 feet, for example, we shall find that the versine is $2\frac{3}{8}$ inches, and this is the cant or super-elevation which must be given to the outer rail.

82.—To find how much a Rail should be bent to suit a Curve.

Rule.—If C be the length of the rail, divide three times C^2 by twice the radius R, these being expressed in feet. The result will give v, the versine expressed in inches; and the rail must be curved until, if a string be stretched from end to end, the distance from the middle of the string to the rail is equal to v.

Formula.—

$$v = \frac{3\,C^2}{2\,R} \quad \ldots\ldots\ldots\ldots \quad (1)$$

where C and R are expressed in feet and v in inches.

Example—Let $C = 24$ feet and $R = 1200$.

$$v = \frac{3 \times 24 \times 24}{2 \times 1200},$$
$$\therefore\ v = \tfrac{3}{4} \text{ inch.}$$

83.—To find the Number of a Crossing.

Rule.—If intersecting strings be laid along the gauge-lines or edges of the crossing, the number I of the crossing is measured by the distance in feet from the intersection of the strings beyond the nose to the point on one string whence the perpendicular offset to the other string is equal to 1 foot.

Example.—If the distance at which the offset is 1 foot be 9′ 9″ the crossing is called a "1 in 9¾," and the number of the crossing is 9·75, or 9¾.

84.—To find the Radius of a Crossing.

Rule.—Multiply I^2, or the square of the number of the crossing (Fig. 2), by twice the gauge, or 2 G. For a closer approximation add 1½ G to the result.

Formula.—

$$R = 3\,G\,I^2 + 1\tfrac{1}{2}\,G \quad . \quad . \quad . \quad . \quad . \quad . \quad (5a)$$

Example.—Let G = 5′ 6″ and I = 8½. Then

$$R = (2 \times 5\tfrac{1}{2} \times 8\tfrac{1}{2} \times 8\tfrac{1}{2}) + 8\tfrac{1}{4},$$

$$\therefore R = 803.$$

Now the accurately calculated radius is 802·99, so that the approximation is wonderfully close.

To test the formula by another example, let G = 3′ 3⅜″ and I = 12. Then

$$R = (2 \times 3{\cdot}2809 \times 12 \times 12) + (1\tfrac{1}{2} \times 3{\cdot}2809);$$

$$\therefore R = 949{\cdot}82,$$

which scarcely differs at all from 949·83, the actual radius.

85.—To find the Curve-lead of a Crossing.

Rule.—According to the gauge, multiply the number of the crossing by the factors indicated in the following formulæ.

Formulæ.—

$$\left.\begin{array}{lll} \text{Gauge.} & & \\ 5'\,6'' & \text{..} \quad \text{..} & L' = 11\,I \\ 5'\,3'' & \text{..} \quad \text{..} & L' = 10\tfrac{1}{2}\,I \\ 5'\,0'' & \text{..} \quad \text{..} & L' = 10\,I \\ 4'\,8\tfrac{1}{2}'' & \text{..} \quad \text{..} & L' = 9\tfrac{1}{2}\,I \\ 3'\,6'' & \text{..} \quad \text{..} & L' = 7\,I \\ \text{metre} & \text{..} \quad \text{..} & L' = 6\tfrac{3}{5}\,I \\ 3'\,0'' & \text{..} \quad \text{..} & L' = 6\,I \\ 2'\,6'' & \text{..} \quad \text{..} & L' = 5\,I \end{array}\right\} \quad \ldots\ldots \; (7c)$$

where L' = curve-lead, and I = number of crossing.

Example.—Let $G = 4'\,8\tfrac{1}{2}''$ and $I = 10$.

Then $$L' = 9\tfrac{1}{2}\,I = 9\tfrac{1}{2} \times 10$$
$$\therefore\ L' = 95 \text{ feet.}$$

The exact curve-lead, given in Table XV., is 94·401, but the difference is not important.

86.—To find the Switch-lead of a Crossing.

Rule.—According to the gauge, multiply the number of the crossing by the factors indicated in the following formulæ.

Formulæ.—

Gauge.

which differs very little from 26·672 feet, the exact switch-lead given in Table XV.

87.—To find the Lead of a Crossing.

Rule.—According to the gauge, multiply the number of the crossing by the factors indicated in the following formulæ; or, subtract the switch-lead (Art. 86) from the curve-lead (Art. 85).

Formulæ.—

$$\left.\begin{array}{lll} \text{Gauge.} & & \\ 5'\ 6'' & \ldots\ \ldots & L = 8\tfrac{1}{4}\ I \\ 5'\ 3'' & \ldots\ \ldots & L = 7\tfrac{4}{5}\ I \\ 5'\ 0' & \ldots\ \ldots & L = 7\tfrac{1}{3}\ I \\ 4'\ 8\tfrac{1}{2}'' & \ldots\ \ldots & L = 6\tfrac{3}{4}\ I \\ 3'\ 6'' & \ldots\ \ldots & L = 4\tfrac{9}{10}\ I \\ \text{metre} & \ldots\ \ldots & L = 4\tfrac{3}{5}\ I \\ 3'\ 0'' & \ldots\ \ldots & L = 4\tfrac{1}{8}\ I \\ 2'\ 6'' & \ldots\ \ldots & L = 3\tfrac{1}{2}\ I \end{array}\right\} \quad \ldots\ (12a)$$

where L = lead of crossing (Fig. 16), and I = the number.

Example.—Let $G = 4'\ 8\tfrac{1}{2}''$ and $I = 10$. Then

$$\begin{aligned} L &= 6\tfrac{3}{4}\ I = 6\tfrac{3}{4} \times 10 \\ &= 67'\ 6' \end{aligned}$$

which is only 2¾ inches less than the exact lead given in Table XV. The difference between the curve-lead, 95′ 0″, and the switch-lead, 26′ 8″, would give us 68′ 4″, so that the direct formula is more correct.

88.—To find the Crossing required in any case.

(1) Turnout with a curve at a given radius from a straight line (Fig. 16).

Formula.—

$$I = \sqrt{\frac{R}{2\,G}} \quad \ldots\ldots\ldots \quad (23)$$

where I = the required number of crossing, R = radius of curve, and $\sqrt{\frac{1}{2\,G}}$ has the following values for different gauges:—

Gauge.	
5′ 6″	0·301515
5′ 3″	0·308607
5′ 0″	0·316228
4′ 8½″	0·325876
3′ 6″	0·377964
metre	0·390381
3′ 0″	0·408248
2′ 6″	0·447214

Example.—On the metre gauge let R = 950. Then

$$
\begin{aligned}
I &= \sqrt{950} \times 0\cdot39 \\
&= 30\cdot82 \times 0\cdot39 \\
&= 12\cdot02
\end{aligned}
$$

so that a 1-in-12 crossing may be used.

(2) Curves of contrary flexure (Fig. 17).

Formula.—

(3) Curves of similar flexure (Fig. 18).

Formula.—

$$1 = \sqrt{\frac{R_1 R_2}{R_1 - R_2}} \times \sqrt{\frac{1}{2 G}} \quad . \ . \ . \ . \ (26b)$$

where R_1 and R_2 are the radii of the curves, which both turn off in the same direction, and $\sqrt{\frac{1}{2 G}}$ has the value indicated above for each gauge.

Example.—Let $G = 5' \ 6''$, $R_1 = 1650$, and $R_2 = 660$. Then

$$I = \sqrt{\frac{1650 \times 660}{1650 + 660}} \times 0 \cdot 302$$

$$= 10$$

so that a 1-in-10 crossing will suit this case also.

CHAPTER V.

89.—Remarks on Signalling and Interlocking.

Fixed signals consist of home, distant, starting and siding signals.

The home signal may be placed at a station (Fig. 38), junction, siding, or signal-box, and is an *absolute stop signal.* It should be placed at a sufficient distance from the fouling point to allow some margin for accidentally drawing a little beyond the signal. No train must pass a home signal at danger, or foul the points or crossings which it protects, except as prescribed in the regulations—e.g., while shunting from one line to the other, or into or out of sidings; or where (at places other than junctions) starting signals are not provided, and it is necessary to bring the train under the protection of the home signal.

The distant signal (as in Fig. 38) is fixed at a sufficient distance (say 1000 yards, or on a rising gradient 800 yards) from the home signal, and is not merely a repeater of the *home* signal, for when a driver sees the distant lowered, he knows that *both the home and the starting signals* have been lowered. When, however, the distant signal is at danger, the driver must be ready to pull up at it, if necessary; but, if the road be clear, he may proceed cautiously (so that he may stop short of any obstruction) and bring his train to a stand as near the home
e circumstances of the case will allow. The distant
be distinguished by a fish-tail notch cut out of the

nals (at stations placed generally at the end of the
advanced starting signals control the departure

of trains into the section ahead, and must not be passed, when at danger, except where it is necessary to shunt over points and crossings or cross-over roads close by, when the signalman may allow the shunting to be carried out under his direction. The starting signal should not be lowered to allow a train to enter the next section until "line clear" has been received from the station in advance. But, where an advanced starting signal is provided and the line is clear, the signalman may, if necessary, after bringing the train to a stand, lower the starting signal to allow such train to proceed to the advanced starting signal, and no further. The advanced starting signal thus marks the limit up to which a train may be drawn forward beyond the starting signal, in order to leave the platform line clear, or for shunting purposes, or other station duties. The advanced starting signal is generally placed (as in Fig. 38) 300 to 350 yards in advance of the cabin, so that a train of maximum length may clear the section in rear without entering the section ahead, and it should be clearly visible to the driver from the platform starting signal, as well as to the signalman in the cabin.

Exit from a siding is controlled by a ground disc or dwarf semaphore siding signal. No train must leave the siding until such signal has been taken off.

All signals should be on separate posts or on brackets. Where there is more than one arm on one side of a post, the first or top arm applies to the line on the left, the second arm to the line next in order from the left, and so on; but if the main or important line be not the one on the left the signals must be on separate posts or brackets.

A distant signal must not back-lap a home or starting signal of a station in rear of it. If on the same post as a home or starting signal, its arm must be placed below, and be slotted with or controlled by the upper signal, so that it cannot possibly be pulled off when the latter is at danger. It is a general rule that lamps should be at least 7 feet apart, so the distant should be 7 feet below the home or starting signal.

At a junction, all distant signals must be controlled by the respective home and starting signal.

Every signal arm must be weighted, so as to fly to danger if the connection between arm and lever should break at any point.

The front signal lights are red for "danger," and green for "all right"; the back light (visible only when the signal is at danger) white. This is not obligatory on existing lines, or on new lines run over by companies using a different system of lights. For the sake of distinction, the danger lights of bay starting and other minor signals are often purple instead of red.

Signals are usually worked by wires, the "slack" of which is better regulated by hand adjusters in the signal-cabin than by self-acting so-called compensators.

Having thus briefly described the functions of fixed signals, their approximate positions, and the requirements of the Board of Trade in regard to them, points and crossings in connection with them must be considered.

Points must be worked or bolted by rods, the effect of varying temperature on rods of 100 feet and upwards in length being corrected by self-acting compensators.

Facing points should be avoided as far as possible. They must not be worked from a greater distance than 180 yards, and should be placed as near as practicable to the levers by which they are actuated. In the case of trailing points on the main line, or safety points of sidings, the limit of distance from the levers is 300 yards. This is the English practice, but on the Continent these limits are considerably exceeded, and with perfect safety.

To secure facing points in their proper position they must be bolted by a locking plunger passing through the stretcher-bar; and, to prevent the signalman from withdrawing the bolt while a train is passing over the points, the plunger must be fitted with a locking-bar to suit the longest wheel-base of the rolling-stock. The plunger and locking-bar may be worked either by a separate lever or by the lever which also works the ts.

The first step towards the interlocking of points and signals is the concentration of the levers in one frame.

The point and signal levers must be so interlocked that a signal cannot be lowered for a train until the points have been properly set and locked; that any two signals which might lead to a collision cannot be exhibited at the same time; and that, after signals have been lowered for a train to pass, no points connected with, or leading to, the line on which the train is running can be moved. Home or starting signals, next in advance of trailing points, when lowered, must lock the points in either position, unless this locking will unduly interfere with the traffic.

Points also, if possible, are to be so interlocked as to avoid the risk of a collision by over-running.

*A distant signal must not be capable of being lowered unless the home and starting signals in advance of it have been lowered.**

Detectors must also be fitted, in order to ensure that the points are properly set before the signals are lowered, and to discover any failure in the connections between the levers and the points. Otherwise, if the rods were buckled or broken, a lever might be pulled over without any corresponding movement of the points.

From the foregoing remarks—in which are included the present requirements of the Board of Trade—it will be seen that there are few absolute rules for the precedence of levers, &c. The interlocking is generally arranged to suit the requirements of the junction or station to which it is applied.

Whenever it is possible, the interlocking of the point levers (independently of the signals) should be so arranged that the various switches may be set to form a trap or protection, when trains are backing or otherwise. The case of an ordinary double junction may be taken as an example (Fig. 39).

If a train from A on the main line is to proceed on the branch towards C over facing points 2, it is necessary, before making the road from main to branch, to turn over points 1, so that, if a train on the other line B B were backed over points 1, it would not foul the train from A when the latter was crossing the main line B B. The order of working would, therefore, be 1, 2, 3, 4, 5. The levers having been put back in reverse order, a train running over facing points 2 on the main line A A would require levers 3, 6, 7 to be pulled over in succession.

---

* In interlocking this means that the distant signal must also be put back to danger before the home and starting signals.

For a train running on the main line B B over trailing points 1 the order would be 3, 10, 11, so that a train coming from the opposite direction on the other main line could not cross it.* If, however, a train from D on the branch were entering the main line over points 1, it would be impossible to trap another train from the main line B B running in the same direction and over the same points. Nevertheless, an accident could only take place through disobedience of signals; for, when the road is made from branch to main line, signal 10 (and, therefore, 11 also) is locked at danger.

Again, where (as in Fig. 40) we have a siding or slip road in a cross-over road, the cross-over points *a* should precede the siding points *b*, which in turn would precede the signal *c*.

It is now required that the starting as well as the home or stop signal shall precede the distant, so that, should a driver approach a station or junction where the distant signal is down, he will know that not only is the station clear but the section in advance also.

If the distant, however, be at danger, and the home signal only is lowered as described below, the driver will know that the station is clear but the section in advance is blocked, and that he must stop at the station until the starting signal is lowered. The rule is that, so long as the starting signal is at danger, the home and distant signals must be kept at danger, except on the near approach of a train which has to stop at the station, when, after the speed of the train has been reduced so as to admit of its entering slowly and being pulled up at the platform, the home signal may be taken off to admit the train, but the starting signal must be kept at danger until the section in advance is clear; in the case of a train not booked to stop, the home signal must not be lowered to admit the train until the train has been brought to a stand.

---

* A passenger train going from A on the main line to C on the branch may be stopped and made to wait for a goods train running on the other main line B B over points 1, as the former can be trapped and a collision averted if the driver over-runs signals, while the latter cannot.

Should the distant and home stand at danger, the driver will know that he must reduce his speed to enable him to stop at the latter.

In all cases the lowering of the distant signal must backlock the home or starting signal levers, so that they cannot be put back until the distant signal has first been put to danger.

In sections where the distance is so short that a distant signal is not required, the home or starting signal should be controlled from the station in advance. This is generally done on the signal itself, although there are cases, but very few, where, in mechanical bolt-locking, the lever is governed or controlled.

The general requirements of a good interlocking apparatus are—

(1) That there shall be very close locking, i.e., the locking shall act as soon as the lever is moved, and the unlocking shall not be effected until the stroke has been completed;

(2) That the locking shall be compactly arranged;

(3) That the locking shall not occupy such space in front of the levers as will prevent the signalman from having the best possible view of the railway, nor such space at the back as will not allow him to stand well up to the levers;

(4) That the locking shall not be arranged vertically, which practically prevents a large cabin from being placed across the lines (the most favourable position);

(5) That, for choice, the locking be arranged in horizontal tiers beneath the floor of the cabin;

(6) That the locking may be easily got at for cleaning,

lubricating, alterations or repairs, and, so far as possible, without occupation;

(7) That there shall be as few wearing parts as possible—the less friction, the less the effort to work the levers, and the less wear and tear of the parts;

(8) That the parts shall be, as far as possible, interchangeable;

(9) That ordinary repairs, alterations or additions may be made without the aid of an expert;

(10) That, although sufficiently sensitive, the apparatus shall not be delicate, or require too much attention;

(11) That its effective working shall not be affected by variation of temperature;

(12) That the apparatus shall be capable of extension, if required;

(13) That the apparatus shall not only be effective in working, but strong, durable, and as simple as possible in construction.

Of course the engineer in India would be glad to have an apparatus that he could turn out of his own shops, but the economy of that in the long run may be doubted.

1.

REPORT ON STEEL RAILS.

Weight of rails, 41¼ lbs. per yard.

Lengths allowed, 94 per cent. 24 ft. .. Weights 330·00 lbs.
" " 4 " 21 " .. " 288·75 "
" " 2 " 18 " .. " 247·50 "

Tests of Section.				Lever Test of 24 ft. Rails on 3 ft. Bearing.									Tests with Falling Weights, 1120 lbs. falling 15 feet.			
Date.	No. of Rails Weighed.	Total Weight in lbs.	Average Weight of 24 ft. Rail.	Date.	10 Tons.	Permanent Set.	12 Tons.	Permanent Set.	15 Tons.	Permanent Set.	20 Tons.	Permanent Set.	Date.	No. of Rails Tested.	Deflexion after one Blow.	Deflexion after two Blows.
March 17 " 21	6 6	1988 1981	330·75 or 41·34 pounds per yard.	March 30	1/8 1/8	Nil. Nil.	5/32 1/8	Nil. Nil.	1/4 3/16	3/32 Nil.	3/8 1/4	13/32 7/32	March 9	6	1 7/8 1 15/16 2 1/16 2 1/8 2 5/16 2 1/16	3 5/8 3 11/16 3 15/16 3 15/16 4 3/8 3 3/4
	12	3969														

STATEMENT OF RAILS TENDERED, ACCEPTED, AND REJECTED.

Date.	Number of Rails Tendered.	Number of Rails Accepted.	Number of Rails rejected, and Nature of Defects.						
			Finally.				Pro tem.		Total.
			Head.	Web.	Flange.	Foot.	Crooked.	Cut Ends.	
March 17	893	861	6	..	6	4	10	6	32
" 18	2,406	2,338	8	..	10	11	20	19	68
" 19	2,754	2,669	3	..	20	16	21	25	85
" 20	3,069	3,005	7	..	9	6	32	10	64
" 21	2,002	1,925	7	..	11	10	33	16	77
Total ..	11,124	10,798	31	..	56	47	116	76	326

II.

S OF STEEL RAILS AND SLEEPERS.

al.	Breaking Weight.		Fractured.		Difference between Original and Fractured Areas.		Elongation in 4 inches.	
Area.	On Original Area.	Per Square Inch.	Section.	Area.	Area.	Per Cent.	Actual.	Per Cent.
·25	8·70	34·80	diam. 0·43	·145	·105	42	$\frac{15}{16}$	23·4
·25	9·77	39·08	0·415	·135	·115	46	$\frac{13}{16}$	20·3
·25	10·00	40·00	0·43	·145	·105	42	$\frac{15}{16}$	23·6
·25	9·59	38·36	0·43	·145	·105	42	1	25·0
							in 2 Inches.	
·250	9·25	37·0	$\frac{3}{4} \times \frac{3}{16}$	·141	·109	43·6	$\frac{9}{16}$	28·1
·250	9·00	36·0	$\frac{13}{16} \times \frac{3}{16}$	·152	·098	29·2	$\frac{9}{16}$	28·1
·266	9·40	35·3	$\frac{3}{4} + \frac{3}{16}$	·141	·125	47·0	$\frac{19}{32}$	29·7
·219	8·50	38·8	$\frac{13}{16} \times \frac{5}{32}$	·127	·092	42·0	$\frac{17}{32}$	26·6
·250	8·05	32·2	$\frac{13}{16} \times \frac{1}{8}$	·102	·148	59·2	$\frac{17}{32}$	26·6
·188	7·85	41·7	$\frac{3}{4} \times \frac{1}{8}$	·094	·094	50·0	$\frac{1}{2}$	25·0

III.

TABLE OF CANT (IN INCHES) REQUIRED FOR DIFFERENT CURVES AND MAXIMUM SPEEDS.

Gauge (G) = 5′ 6″ = 5′·5000.

$$E = 4{\cdot}4091 \times \frac{V^2}{R}.$$

Radius. R.	Maximum Speed in Miles per hour.					
	10	20	25	30	40	50
400	1⅛	4⅜	6⅞	..	..	..
600	¾	3	4⅝	6⅝	..	..
800	½	2¼	3½	5	..	..
1000	..	1¾	2¾	4	7	..
1500	..	1¼	1⅞	2⅝	4¾	7⅜
2000	..	⅞	1⅜	2	3½	5½
2500	..	¾	1⅛	1⅝	2¾	4⅜
5000	..	..	½	¾	1⅜	2¼

TABLE OF CHORDS (IN FEET), THE VERSINES OF WHICH ARE EQUAL TO THE REQUIRED CANT.

$$C = 1{\cdot}72 \times V$$

Any	17	34½	43	51½	69	86

IV.

TABLE OF CANT (IN INCHES) REQUIRED FOR DIFFERENT CURVES AND MAXIMUM SPEEDS.

Gauge (G) = 5′ 3″ = 5′·2500.

$$E = 4{\cdot}2087 \times \frac{V^2}{R}.$$

Radius. R.	Maximum Speed in Miles per hour.					
	20	25	30	40	50	60
400	4¼	6½	..	..	..	..
600	2¾	4⅜	6¼	..	..	..
800	2⅛	3¼	4¾	..	..	..
1000	1¾	2⅝	3¾	6¾	..	..
1500	1⅛	1¾	2½	4½	7	..
2000	⅞	1¼	1⅞	3⅜	5¼	7½
2500	[redacted]	1	[redacted]	[redacted]	[redacted]	6

V.

TABLE OF CANT (IN INCHES) REQUIRED FOR DIFFERENT CURVES AND MAXIMUM SPEEDS.

Gauge (G) = 5′ 0″ = 5′·0000.

$$E = 4 \cdot 0083 \times \frac{V^2}{R}.$$

Radius. R.	Maximum Speed in Miles per hour.					
	20	25	30	40	50	60
400	4	6¼	..	..	..	..
600	2⅝	4⅛	6	..	..	..
800	2	3⅛	4½	..	..	..
1000	1⅝	2½	3⅝	6⅜	..	..
1500	1	1⅝	2⅜	4¼	6⅝	..
2000	¾	1¼	1¾	3¼	5	7½
2500	..	1	1½	2½	4	5¾
5000	..	..	¾	1¼	2	2⅞

TABLE OF CHORDS (IN FEET), THE VERSINES OF WHICH ARE EQUAL TO THE REQUIRED CANT.

$$C = 1 \cdot 64 \times V.$$

Any	33	41	49	65½	82	98½

VI.

TABLE OF CANT (IN INCHES) REQUIRED FOR DIFFERENT CURVES AND MAXIMUM SPEEDS.

Gauge (G) = 4′ 8½″ = 4′·7083.

$$E = 3\cdot7744 \times \frac{V^2}{R}.$$

Radius. R.	Maximum Speed in Miles per hour.					
	20	25	30	40	50	60
400	3¾	5⅞	..	..	..	..
600	2½	4	5⅝	..	..	..
800	1⅞	3	4¼	..	..	..
1000	1½	2⅜	3⅜	6	..	..
1500	1	1½	2¼	4	6¼	..
2000	¾	1¼	1¾	3	4¾	6¾
2500	⅝	1	1⅜	2⅜	3¾	5½

VII.

TABLE OF CANT (in inches) Required for Different Curves and Maximum Speeds.

Gauge (G) = 3′ 6″ = 3′·500.

$$E = 2\cdot8058 \times \frac{V^2}{R}.$$

Radius. R.	Maximum Speed in Miles per hour.					
	10	15	20	25	30	40
400	¾	1½	2¾	4⅜	..	..
600	½	1	1⅞	2⅞	4¼	..
800	..	¾	1⅜	2¼	3⅛	..
1000	..	⅝	1⅛	1¾	2½	4½
1500	..	⅜	¾	1⅛	1¾	3
2000	..	..	½	⅞	1¼	2¼
2500	..	..	..	¾	1	1¾
5000	..	..	..	..	½	⅞

TABLE OF CHORDS (in feet), the Versines of which are equal to the Required Cant.

$$C = 1\cdot372 \times V.$$

Any	13½	20½	27½	34	41	55

VIII.

TABLE OF CANT (IN INCHES) REQUIRED FOR DIFFERENT CURVES AND MAXIMUM SPEEDS.

Gauge (G) = 3' 3⅜" = 3·'2809.

$$E = 2{\cdot}6302 \times \frac{V^2}{R}.$$

Radius. R.	Maximum Speed in Miles per hour.					
	10	15	20	25	30	40
400	¾	1½	2⅝	4⅛	5⅞	..
600	½	1	1¾	2¾	4	..
800	..	¾	1¼	2	3	5¼
1000	..	⅝	1	1⅝	2⅜	4¼
1500	..	..	¾	1⅛	1½	2¾
2000	..	..	½	¾	1¼	2⅛

IX.

TABLE OF CANT (IN INCHES) REQUIRED FOR DIFFERENT CURVES AND MAXIMUM SPEEDS.

Gauge (G) = 3′ 0″ = 3′·0000.

$$E = 2\cdot405 \times \frac{V^2}{R}.$$

Radius. R.	Maximum Speed in Miles por hour.					
	10	15	20	25	30	40
400	⅝	1⅜	2⅜	3¼	..	..
600	⅜	⅞	1⅝	2⅛	3⅝	..
800	..	⅝	1¼	1⅝	2¾	4¾
1000	..	½	⅞	1¼	2⅛	3⅞
1500	..	⅜	⅝	⅞	1½	2½
2000	..	..	½	⅝	1⅛	1⅞
2500	..	..	..	½	⅞	1½
5000	..	..	..	..	⅜	¾

TABLE OF CHORDS (IN FEET), THE VERSINES OF WHICH ARE EQUAL TO THE REQUIRED CANT.

$$C = 1\cdot27017 \times V.$$

Any	12½	19	25½	32	38	51

X.

TABLE OF MIDDLE ORDINATES

(IN INCHES),

FOR RAILS OF CERTAIN LENGTHS LAID ON CURVES OF DIFFERENT RADII.

On Curves, whose radius is R.	Middle Ordinates in inches for Rails, whose lengths are						
	40 ft.	30 ft.	27 ft.	24 ft.	21 ft.	18 ft.	15 ft.
	$\frac{2400}{R}$	$\frac{1350}{R}$	$\frac{1093\cdot5}{R}$	$\frac{864}{R}$	$\frac{661\cdot5}{R}$	$\frac{486}{R}$	$\frac{337\cdot5}{R}$
1000	$2\frac{13}{32}$	$1\frac{11}{32}$	$1\frac{3}{32}$	$\frac{7}{8}$	$\frac{21}{32}$	$\frac{1}{2}$	$\frac{11}{32}$
900	$2\frac{21}{32}$	$1\frac{1}{2}$	$1\frac{7}{32}$	$\frac{31}{32}$	$\frac{3}{4}$	$\frac{17}{32}$	$\frac{3}{8}$
800	3	$1\frac{11}{16}$	$1\frac{3}{8}$	$1\frac{1}{16}$	$\frac{13}{16}$	$\frac{5}{8}$	$\frac{7}{16}$

XI.—POINTS AND CROSSINGS.

For all Guages.—Table of Numbers, Angles, and Numerical Values of Factors and Terms which appear in many of the Formulæ.

Number. I.	Angle. α.			$1 + I^2$.	$\sqrt{1 + I^2}$.	$I\sqrt{1 + I^2}$.	$\sqrt{1 + I^2} + I$.	$1 + I^2 + I\sqrt{1 + I^2}$.
	°	′	″					
5	11	18	36	26	5·099	25·495	10·099	51·495
5½	10	18	17	31·25	5·590	30·746	11·090	61·996
6	9	27	44	37	6·083	36·497	12·083	73·497
6½	8	44	46	43·25	6·577	42·747	13·077	85·997
7	8	7	48	50	7·071	49·498	14·071	99·498
7½	7	35	41	57·25	7·566	56 748	15·066	113·998
8	7	7	30	65	8·062	64·498	16·062	129·498
8½	6	42	35	73·25	8·559	72·748	17·059	145·998
9	6	20	25	82	9·055	81·499	18·055	163·499
9½	6	0	32	91·25	9·553	90·749	19·053	181·999
10	5	42	38	101	10·050	100·499	20·050	201·499
10½	5	26	25	111·25	10·548	110·749	21·048	221·999
11	5	11	40	122	11·045	121·499	22·045	243·499
11½	4	58	11	133·25	11·543	132·749	23·043	265 999
12	4	45	49	145	12·042	144·499	24·042	289·499
12½	4	34	26	157·25	12·540	156·749	25·040	313·999
13	4	23	55	170	13·038	169·499	26·038	339·499
13½	4	14	11	183·25	13·537	182·749	27·037	365·999
14	4	5	8	197	14·036	196·499	28·036	393·499
14½	3	56	43	211·25	14·534	210·749	29·034	421·999
15	3	48	51	226	15·033	225·499	30·033	451·499
15½	3	41	29	241·25	15·532	240·749	31·032	481·999
16	3	34	35	257	16·031	256·499	32·031	513·499

XII.—POINTS ANI

TABLE OF NUMBERS, RADII, CURVE-LEADS

Gauge (G) = 5′ 6″ = 5′·5.

APPROXIMATI

$R = 11\ I^2 + 8{\cdot}25.$ $L' = 11\ I + \frac{2{\cdot}75}{I}$

Number. I.	Radius. R.	Curve-lead. L′.	Switch-lead. l′.	Lead. L.
5	283·223	55·544	14·156	41 4¾
5½	340·977	60·996	15·533	45 5½
6	404·231	66·455	16·914	49 6½
6½	472·984	71·921	18·296	53 7½
7	547·236	77·391	19·680	57 8½
7½	626·988	82·865	21·066	61 9½
8	712·239	88·343	22·453	65 10¾
8½	802·991	93·822	23·841	69 11¾
9	899·242	99·305	25·230	74 1
9½	1000·992	104·789	26·619	78 2

CROSSINGS.

Switch-leads, and Leads; Turnouts and Crossovers.

Clearance (d) = $4\frac{1}{4}''$ = $0'{\cdot}354$.

Formulæ.

$$l' = 2{\cdot}7907\,I + \frac{1{\cdot}0125}{I}. \qquad L = 8{\cdot}2093\,I + \frac{1{\cdot}7375}{I}$$

Turnouts and Crossovers.	
Straight Intermediate Portion. S	Curved Intermediate Portion. S.
$5\ D - 55{\cdot}544$	$\sqrt{D\ (1{,}121{\cdot}892 - D)} - 111{\cdot}088$
$5\frac{1}{2}\ D - 60{\cdot}996$	$\sqrt{D\ (1{,}352{\cdot}908 - D)} - 121{\cdot}992$
$6\ D - 66{\cdot}455$	$\sqrt{D\ (1{,}605{\cdot}924 - D)} - 132{\cdot}910$
$6\frac{1}{2}\ D - 71{\cdot}921$	$\sqrt{D\ (1{,}880{\cdot}936 - D)} - 143{\cdot}842$
$7\ D - 77{\cdot}391$	$\sqrt{D\ (2{,}177{\cdot}944 - D)} - 154{\cdot}782$
$7\frac{1}{2}\ D - 82{\cdot}865$	$\sqrt{D\ (2{,}496{\cdot}952 - D)} - 165{\cdot}730$
$8\ D - 88{\cdot}343$	$\sqrt{D\ (2{,}837{\cdot}956 - D)} - 176{\cdot}686$
$8\frac{1}{2}\ D - 93{\cdot}822$	$\sqrt{D\ (3{,}200{\cdot}964 - D)} - 187{\cdot}644$
$9\ D - 99{\cdot}305$	$\sqrt{D\ (3{,}585{\cdot}968 - D)} - 198{\cdot}610$
$9\frac{1}{2}\ D - 104{\cdot}789$	$\sqrt{D\ (3{,}992{\cdot}968 - D)} - 209{\cdot}578$
$10\ D - 110{\cdot}274$	$\sqrt{D\ (4{,}421{\cdot}972 - D)} - 220{\cdot}548$
$10\frac{1}{2}\ D - 115{\cdot}761$	$\sqrt{D\ (4{,}472{\cdot}972 - D)} - 231{\cdot}562$
$11\ D - 121{\cdot}250$	$\sqrt{D\ (5{,}345{\cdot}976 - D)} - 242{\cdot}500$
$11\frac{1}{2}\ D - 126{\cdot}739$	$\sqrt{D\ (5{,}840{\cdot}976 - D)} - 253{\cdot}478$
$12\ D - 132{\cdot}229$	$\sqrt{D\ (6{,}357{\cdot}980 - D)} - 264{\cdot}458$
$12\frac{1}{2}\ D - 137{\cdot}720$	$\sqrt{D\ (6{,}896{\cdot}976 - D)} - 275{\cdot}440$
$13\ D - 143{\cdot}209$	$\sqrt{D\ (7{,}457{\cdot}976 - D)} - 286{\cdot}418$
$13\frac{1}{2}\ D - 148{\cdot}703$	$\sqrt{D\ (8{,}040{\cdot}976 - D)} - 297{\cdot}406$
$14\ D - 154{\cdot}198$	$\sqrt{D\ (8{,}645{\cdot}976 - D)} - 308{\cdot}396$
$14\frac{1}{2}\ D - 159{\cdot}687$	$\sqrt{D\ (9{,}272{\cdot}976 - D)} - 319{\cdot}374$
$15\ D - 165{\cdot}181$	$\sqrt{D\ (9{,}921{\cdot}976 - D)} - 330{\cdot}362$
$15\frac{1}{2}\ D - 170{\cdot}676$	$\sqrt{D\ (10{,}592{\cdot}976 - D)} - 341{\cdot}352$
$16\ D - 176{\cdot}170$	$\sqrt{D\ (11{,}285{\cdot}976 - D)} - 352{\cdot}340$

L

XIII.—POINTS AN

TABLE OF NUMBERS, RADII, CURVE-LEAD

Gauge (G) = 5′ 3″ = 5′·25.

APPROXIMA

$$R = 10{\cdot}5\,I^2 + 7{\cdot}87. \qquad L' = 10{\cdot}5\,I + \frac{2{\cdot}625}{I}.$$

Number. I.	Radius. R.	Curve-lead. L′.	Switch-lead. l′.	Lead. L.
				′ ″
5	270·349	53·020	13·830	39 2¼
5½	325·478	58·224	15·176	43 0½
6	385·857	63·435	16·525	46 11
6½	451·485	68·652	17·875	50 9¼
7	522·362	73·873	19·228	54 7¾
7½	598·488	79·099	20·582	58 6¼
8	679·865	84·327	21·937	62 4¾
8½	766·491	89·558	23·293	66 3¼
9	858·367	94·791	24·650	70 1¾
9½	955·493	100·026	26·007	74 0¼

CROSSINGS.

SWITCH-LEADS, AND LEADS; TURNOUTS AND CROSSOVERS.

Clearance (d) = 4¼″ = 0′·354.

FORMULÆ.

$$l' = 2\cdot7267\,\mathrm{I} + \frac{0\cdot985}{\mathrm{I}}. \qquad \mathrm{L} = 7\cdot7733\,\mathrm{I} + \frac{1\cdot64}{\mathrm{I}}.$$

TURNOUTS AND CROSSOVERS.

Straight Intermediate Portion. S.	Curved Intermediate Portion. S.
5 D – 53·020	$\sqrt{\mathrm{D}\,(1{,}080\cdot896 - \mathrm{D})} - 106\cdot040$
5½ D – 58·224	$\sqrt{\mathrm{D}\,(1{,}291\cdot412 - \mathrm{D})} - 116\cdot448$
6 D – 63·435	$\sqrt{\mathrm{D}\,(1{,}532\cdot928 - \mathrm{D})} - 126\cdot870$
6½ D – 68·652	$\sqrt{\mathrm{D}\,(1{,}795\cdot440 - \mathrm{D})} - 137\cdot304$
7 D – 73·873	$\sqrt{\mathrm{D}\,(2{,}078\cdot948 - \mathrm{D})} - 147\cdot746$
7½ D – 79·099	$\sqrt{\mathrm{D}\,(2{,}383\cdot452 - \mathrm{D})} - 158\cdot198$
8 D – 84·327	$\sqrt{\mathrm{D}\,(2{,}708\cdot960 - \mathrm{D})} - 168\cdot654$
8½ D – 89·558	$\sqrt{\mathrm{D}\,(3{,}055\cdot464 - \mathrm{D})} - 179\cdot116$
9 D – 94·791	$\sqrt{\mathrm{D}\,(3{,}422\cdot968 - \mathrm{D})} - 189\cdot582$
9½ D – 100·026	$\sqrt{\mathrm{D}\,(3{,}811\cdot472 - \mathrm{D})} - 200\cdot052$
10 D – 105·262	$\sqrt{\mathrm{D}\,(4{,}220\cdot976 - \mathrm{D})} - 210\cdot524$
10½ D – 110·499	$\sqrt{\mathrm{D}\,(4{,}651\cdot476 - \mathrm{D})} - 220\cdot998$
11 D – 115·738	$\sqrt{\mathrm{D}\,(5{,}102\cdot980 - \mathrm{D})} - 231\cdot476$
11½ D – 120·978	$\sqrt{\mathrm{D}\,(5{,}575\cdot480 - \mathrm{D})} - 241\cdot956$
12 D – 126·218	$\sqrt{\mathrm{D}\,(6{,}068\cdot980 - \mathrm{D})} - 252\cdot436$
12½ D – 131·460	$\sqrt{\mathrm{D}\,(6{,}583\cdot480 - \mathrm{D})} - 262\cdot920$
13 D – 136·699	$\sqrt{\mathrm{D}\,(7{,}118\cdot980 - \mathrm{D})} - 273\cdot398$
13½ D – 141·944	$\sqrt{\mathrm{D}\,(7{,}675\cdot480 - \mathrm{D})} - 283\cdot888$
14 D – 147·189	$\sqrt{\mathrm{D}\,(8{,}252\cdot980 - \mathrm{D})} - 294\cdot378$
14½ D – 152·428	$\sqrt{\mathrm{D}\,(5{,}851\cdot480 - \mathrm{D})} - 304\cdot856$
15 D – 157·673	$\sqrt{\mathrm{D}\,(9{,}470\cdot980 - \mathrm{D})} - 315\cdot346$
15½ D – 162·918	$\sqrt{\mathrm{D}\,(10{,}111\cdot480 - \mathrm{D})} - 325\cdot836$
16 D – 168·163	$\sqrt{\mathrm{D}\,(10{,}772\cdot980 - \mathrm{D})} - 336\cdot326$

XIV.—POINTS ANI

TABLE OF NUMBERS, RADII, CURVE-LEADS

Gauge (G) = 5′ 0″ = 5′·00.

APPROXIMATI

$$R = 10\,I^2 + 7{\cdot}5. \qquad L' = 10\,I + \frac{2{\cdot}5}{I}.$$

Number. I.	Radius. R.	Curve-lead. L′.	Switch-lead. l′.	Lead. L.	
				′	″
5	257·475	50.495	13·497	37	0
5½	309·980	55·450	14·810	40	7¾
6	367·485	60·415	16·126	44	3½
6½	429·985	65·385	17·444	47	11¼
7	497·490	70·355	18·764	51	7
7½	569·990	75·330	20·085	55	3
8	647·490	80·310	21·407	58	10¾
8½	729·990	85·295	22·731	62	6¾
9	817·495	90·275	24·055	66	2¾
9½	909·995	95·265	25·380	69	10½

CROSSINGS.

SWITCH-LEADS, AND LEADS; TURNOUTS AND CROSSOVERS.

Clearance $(d) = 4\frac{1}{4}'' = 0'\cdot354$.

FORMULÆ.

$$r = 2\cdot6609\,I + \frac{0\cdot9635}{I}. \qquad L = 7\cdot3388\,I + \frac{1\cdot5197}{I}.$$

TURNOUTS AND CROSSOVERS.	
Straight Intermediate Portion. S.	Curved Intermediate Portion. S.
$5\ D - 50\cdot495$	$\sqrt{D(1,019\cdot900 - D)} - 100\cdot990$
$5\frac{1}{2}\ D - 55\cdot450$	$\sqrt{D(1,229\cdot920 - D)} - 110\cdot900$
$6\ D - 60\cdot415$	$\sqrt{D(1,459\cdot940 - D)} - 120\cdot830$
$6\frac{1}{2}\ D - 65\cdot385$	$\sqrt{D(1,709\cdot940 - D)} - 130\cdot770$
$7\ D - 70\cdot355$	$\sqrt{D(1,979\cdot960 - D)} - 140\cdot710$
$7\frac{1}{2}\ D - 75\cdot330$	$\sqrt{D(2,269\cdot960 - D)} - 150\cdot660$
$8\ D - 80\cdot310$	$\sqrt{D(2,579\cdot960 - D)} - 160\cdot620$
$8\frac{1}{2}\ D - 85\cdot295$	$\sqrt{D(2,909\cdot960 - D)} - 170\cdot590$
$9\ D - 90\cdot275$	$\sqrt{D(3,259\cdot960 - D)} - 180\cdot550$
$9\frac{1}{2}\ D - 95\cdot265$	$\sqrt{D(3,629\cdot980 - D)} - 190\cdot530$
$10\ D - 100\cdot250$	$\sqrt{D(4,019\cdot980 - D)} - 200\cdot500$
$10\frac{1}{2}\ D - 105\cdot240$	$\sqrt{D(4,429\cdot980 - D)} - 210\cdot480$
$11\ D - 110\cdot225$	$\sqrt{D(4,859\cdot980 - D)} - 220\cdot450$
$11\frac{1}{2}\ D - 115\cdot215$	$\sqrt{D(5,309\cdot980 - D)} - 230\cdot430$
$12\ D - 120\cdot210$	$\sqrt{D(5,779\cdot980 - D)} - 240\cdot420$
$12\frac{1}{2}\ D - 125\cdot200$	$\sqrt{D(6,269\cdot980 - D)} - 250\cdot400$
$13\ D - 130\cdot190$	$\sqrt{D(6,779\cdot980 - D)} - 260\cdot380$
$13\frac{1}{2}\ D - 135\cdot185$	$\sqrt{D(7,309\cdot980 - D)} - 270\cdot370$
$14\ D - 140\cdot180$	$\sqrt{D(7,859\cdot980 - D)} - 280\cdot360$
$14\frac{1}{2}\ D - 145\cdot170$	$\sqrt{D(8,429\cdot980 - D)} - 290\cdot340$
$15\ D - 150\cdot165$	$\sqrt{D(9,019\cdot980 - D)} - 300\cdot330$
$15\frac{1}{2}\ D - 155\cdot160$	$\sqrt{D(9,629\cdot980 - D)} - 310\cdot320$
$16\ D - 160\cdot150$	$\sqrt{D(10,259\cdot980 - D)} - 320\cdot300$

XV.—POINTS AND

Table of Numbers, Radii, Curve-leads,

Gauge (G) = 4′ 8½″ = 4′·7083.

Approximate

$$R = 9{\cdot}4166\,I^2 + 7{\cdot}06. \qquad L' = 9{\cdot}4166\,I + \frac{2{\cdot}354}{I}.$$

Number. I.	Radius. R.	Curve-lead. L′.	Switch-lead. l′.	Lead. L.
				′ ″
5	242·454	47·549	13·480	34 0¾
5½	291·895	52·216	14·791	37 5
6	346·044	56·890	16·106	40 9½
6½	404·900	61·568	17·422	44 1¾
7	468·464	66·251	18·740	47 6¼
7½	536·736	70·937	20·060	50 10½
8	609·716	75·626	21·381	54 3
8½	687·404	80·317	22·703	57 7¼
9	769·800	85·010	24·025	60 11¾
9½	856·904	89·705	25·348	64 4¼

CROSSINGS.

SWITCH-LEADS, AND LEADS; TURNOUTS AND CROSSOVERS.

Clearance (d) = $4\frac{1}{2}''$ = $0'{\cdot}375$.

FORMULÆ.

$$l' = 2{\cdot}6575\,\mathrm{I} + \frac{0{\cdot}964}{\mathrm{I}}. \qquad \mathrm{L} = 6{\cdot}759\,\mathrm{I} + \frac{1{\cdot}39}{\mathrm{I}}.$$

TURNOUTS AND CROSSOVERS.	
Straight Intermediate Portion. S.	Curved Intermediate Portion. S.
$5\ \mathrm{D} - 47{\cdot}549$	$\sqrt{\mathrm{D}\,(960{\cdot}399 - \mathrm{D})} - 95{\cdot}098$
$5\frac{1}{2}\ \mathrm{D} - 52{\cdot}216$	$\sqrt{\mathrm{D}\,(1158{\cdot}163 - \mathrm{D})} - 104{\cdot}432$
$6\ \mathrm{D} - 56{\cdot}890$	$\sqrt{\mathrm{D}\,(1374{\cdot}759 - \mathrm{D})} - 113{\cdot}780$
$6\frac{1}{2}\ \mathrm{D} - 61{\cdot}568$	$\sqrt{\mathrm{D}\,(1610{\cdot}183 - \mathrm{D})} - 123{\cdot}136$
$7\ \mathrm{D} - 66{\cdot}251$	$\sqrt{\mathrm{D}\,(1864{\cdot}439 - \mathrm{D})} - 132{\cdot}502$
$7\frac{1}{2}\ \mathrm{D} - 70{\cdot}937$	$\sqrt{\mathrm{D}\,(2137{\cdot}527 - \mathrm{D})} - 141{\cdot}874$
$8\ \mathrm{D} - 75{\cdot}626$	$\sqrt{\mathrm{D}\,(2429{\cdot}447 - \mathrm{D})} - 151{\cdot}252$
$8\frac{1}{2}\ \mathrm{D} - 80{\cdot}317$	$\sqrt{\mathrm{D}\,(2740{\cdot}199 - \mathrm{D})} - 160{\cdot}634$
$9\ \mathrm{D} - 85{\cdot}010$	$\sqrt{\mathrm{D}\,(3069{\cdot}783 - \mathrm{D})} - 170{\cdot}020$
$9\frac{1}{2}\ \mathrm{D} - 89{\cdot}705$	$\sqrt{\mathrm{D}\,(3418{\cdot}199 - \mathrm{D})} - 179{\cdot}410$
$10\ \mathrm{D} - 94{\cdot}401$	$\sqrt{\mathrm{D}\,(3785{\cdot}431 - \mathrm{D})} - 188{\cdot}802$
$10\frac{1}{2}\ \mathrm{D} - 99{\cdot}098$	$\sqrt{\mathrm{D}\,(4171{\cdot}531 - \mathrm{D})} - 198{\cdot}196$
$11\ \mathrm{D} - 103{\cdot}796$	$\sqrt{\mathrm{D}\,(4576{\cdot}427 - \mathrm{D})} - 207{\cdot}592$
$11\frac{1}{2}\ \mathrm{D} - 108{\cdot}495$	$\sqrt{\mathrm{D}\,(5000{\cdot}195 - \mathrm{D})} - 216{\cdot}990$
$12\ \mathrm{D} - 113{\cdot}195$	$\sqrt{\mathrm{D}\,(5442{\cdot}775 - \mathrm{D})} - 226{\cdot}390$
$12\frac{1}{2}\ \mathrm{D} - 117{\cdot}896$	$\sqrt{\mathrm{D}\,(5904{\cdot}187 - \mathrm{D})} - 235{\cdot}792$
$13\ \mathrm{D} - 122{\cdot}595$	$\sqrt{\mathrm{D}\,(6384{\cdot}427 - \mathrm{D})} - 245{\cdot}190$
$13\frac{1}{2}\ \mathrm{D} - 127{\cdot}298$	$\sqrt{\mathrm{D}\,(6883{\cdot}503 - \mathrm{D})} - 254{\cdot}596$
$14\ \mathrm{D} - 132{\cdot}002$	$\sqrt{\mathrm{D}\,(7401{\cdot}423 - \mathrm{D})} - 264{\cdot}004$
$14\frac{1}{2}\ \mathrm{D} - 136{\cdot}701$	$\sqrt{\mathrm{D}\,(7938{\cdot}175 - \mathrm{D})} - 273{\cdot}402$
$15\ \mathrm{D} - 141{\cdot}404$	$\sqrt{\mathrm{D}\,(8493{\cdot}763 - \mathrm{D})} - 282{\cdot}808$
$15\frac{1}{2}\ \mathrm{D} - 146{\cdot}108$	$\sqrt{\mathrm{D}\,(9068{\cdot}187 - \mathrm{D})} - 292{\cdot}216$
$16\ \mathrm{D} - 150{\cdot}811$	$\sqrt{\mathrm{D}\,(9661{\cdot}415 - \mathrm{D})} - 301{\cdot}622$

XVI.—POINTS AND

Table of Numbers, Radii, Curve-leads,

Gauge (G) = 3′ 6″ = 3′·5.

Approximate

$$R = 7\,I^2 + 5{\cdot}25. \qquad L' = 7\,I + \frac{1{\cdot}75}{I}.$$

Number. I.	Radius. R.	Curve-lead. L′.	Switch-lead. l'.	Lead. L.
				′ ″
5	180·233	35·346	10·609	24 8¾
5½	216·986	38·816	11·641	27 2
6	257·238	42·290	12·676	29 7¼
6½	300·990	45·678	13·712	32 0¾
7	348·241	49·249	14·750	34 6
7½	398·992	52·732	15·788	36 11¼
8	453·243	56·218	16·828	39 4¾
8½	510·994	59·705	17·868	41 10
9	572·245	63·194	18·909	44 3½
9½	636·995	66·684	19·951	46 8¾

CROSSINGS.

SWITCH-LEADS, AND LEADS; TURNOUTS AND CROSSOVERS.

Clearance (d) = 3¾" = 0'·3125.

FORMULÆ.

$$l' = 2{\cdot}0917\,I + \frac{0{\cdot}752}{I}. \qquad L = 4{\cdot}9083\,I + \frac{0{\cdot}998}{I}.$$

TURNOUTS AND CROSSOVERS.	
Straight Intermediate Portion. S.	Curved Intermediate Portion. S.
$5\,D - 35{\cdot}346$	$\sqrt{D\,(713{\cdot}932 - D)} - 70{\cdot}692$
$5\tfrac{1}{2}\,D - 38{\cdot}816$	$\sqrt{D\,(860{\cdot}944 - D)} - 77{\cdot}632$
$6\,D - 42{\cdot}290$	$\sqrt{D\,(1021{\cdot}952 - D)} - 84{\cdot}580$
$6\tfrac{1}{2}\,D - 45{\cdot}678$	$\sqrt{D\,(1196{\cdot}960 - D)} - 91{\cdot}356$
$7\,D - 48{\cdot}249$	$\sqrt{D\,(1386{\cdot}964 - D)} - 98{\cdot}498$
$7\tfrac{1}{2}\,D - 52{\cdot}732$	$\sqrt{D\,(1588{\cdot}968 - D)} - 105{\cdot}464$
$8\,D - 56{\cdot}218$	$\sqrt{D\,(1805{\cdot}972 - D)} - 112{\cdot}436$
$8\tfrac{1}{2}\,D - 59{\cdot}705$	$\sqrt{D\,(2036{\cdot}976 - D)} - 119{\cdot}410$
$9\,D - 63{\cdot}194$	$\sqrt{D\,(2281{\cdot}980 - D)} - 126{\cdot}388$
$9\tfrac{1}{2}\,D - 66{\cdot}684$	$\sqrt{D\,(2540{\cdot}980 - D)} - 133{\cdot}368$
$10\,D - 70{\cdot}175$	$\sqrt{D\,(2813{\cdot}984 - D)} - 140{\cdot}350$
$10\tfrac{1}{2}\,D - 73{\cdot}666$	$\sqrt{D\,(3100{\cdot}984 - D)} - 147{\cdot}332$
$11\,D - 77{\cdot}159$	$\sqrt{D\,(3401{\cdot}984 - D)} - 154{\cdot}318$
$11\tfrac{1}{2}\,D - 80{\cdot}652$	$\sqrt{D\,(3716{\cdot}988 - D)} - 161{\cdot}304$
$12\,D - 84{\cdot}146$	$\sqrt{D\,(4045{\cdot}988 - D)} - 168{\cdot}292$
$12\tfrac{1}{2}\,D - 87{\cdot}640$	$\sqrt{D\,(4388{\cdot}984 - D)} - 175{\cdot}280$
$13\,D - 91{\cdot}133$	$\sqrt{D\,(4745{\cdot}984 - D)} - 182{\cdot}266$
$13\tfrac{1}{2}\,D - 94{\cdot}629$	$\sqrt{D\,(5116{\cdot}984 - D)} - 189{\cdot}258$
$14\,D - 98{\cdot}126$	$\sqrt{D\,(5501{\cdot}984 - D)} - 196{\cdot}252$
$14\tfrac{1}{2}\,D - 101{\cdot}619$	$\sqrt{D\,(5900{\cdot}984 - D)} - 203{\cdot}238$
$15\,D - 105{\cdot}115$	$\sqrt{D\,(6313{\cdot}984 - D)} - 210{\cdot}230$
$15\tfrac{1}{2}\,D - 108{\cdot}612$	$\sqrt{D\,(6740{\cdot}984 - D)} - 217{\cdot}224$
$16\,D - 112{\cdot}108$	$\sqrt{D\,(7181{\cdot}984 - D)} - 224{\cdot}216$

XVII.—POINTS AND

TABLE OF NUMBERS, RADII, CURVE-LEADS,

Gauge (G) = 3′ 3⅜″ = 3′·2809.

APPROXIMATE

$R = 6{\cdot}5618\,I^2 + 4{\cdot}921.$ $L' = 6{\cdot}5618\,I + \frac{1{\cdot}64}{I}.$

Number. I.	Radius. R.	Curve-lead. L′.	Switch-lead. l′.	Lead. L.
				′ ″
5	168·950	33·134	10·097	23 0½
5½	203·402	36·386	11·080	25 3¾
6	241·135	39·644	12·065	27 7
6½	282·148	42·903	13·051	29 10¼
7	326·441	46·166	14·039	32 1½
7½	374·015	49·431	15·027	34 4¾
8	424·870	52·699	16·016	36 8¼
8½	479·006	55·967	17·007	38 11½
9	536·425	59·238	17·997	41 3
9½	597·119	62·509	18·989	43 6¼

CROSSINGS.

SWITCH-LEADS, AND LEADS; TURNOUTS AND CROSSOVERS.

Clearance (d) = $3\frac{5}{8}''$ = $0'\cdot302$.

FORMULÆ.

$$l' = 1\cdot9908\,I + \frac{0\cdot72}{I}. \qquad L = 4\cdot5708\,I + \frac{0\cdot92}{I}.$$

TURNOUTS AND CROSSOVERS.	
Straight Intermediate Portion. S.	Curved Intermediate Portion. S.
5 D − 33·134	$\sqrt{D(\ 669\cdot238 - D)} - 66\cdot268$
5½ D − 36·386	$\sqrt{D(\ 807\cdot046 - D)} - 72\cdot772$
6 D − 39·644	$\sqrt{D(\ 957\cdot978 - D)} - 79\cdot288$
6½ D − 42·903	$\sqrt{D(1122\cdot030 - D)} - 85\cdot806$
7 D − 46·166	$\sqrt{D(1299\cdot202 - D)} - 92\cdot332$
7½ D − 49·431	$\sqrt{D(1089\cdot498 - D)} - 98\cdot862$
8 D − 52·699	$\sqrt{D(1692\cdot918 - D)} - 105\cdot398$
8½ D − 55·967	$\sqrt{D(1909\cdot462 - D)} - 111\cdot934$
9 D − 59·238	$\sqrt{D(2139\cdot138 - D)} - 118\cdot476$
9½ D − 62·509	$\sqrt{D(2381\cdot914 - D)} - 125\cdot018$
10 D − 65·782	$\sqrt{D(2637\cdot826 - D)} - 131\cdot564$
10½ D − 69·005	$\sqrt{D(2906\cdot862 - D)} - 138\cdot010$
11 D − 72·329	$\sqrt{D(3189\cdot022 - D)} - 144\cdot658$
11½ D − 75·603	$\sqrt{D(3484\cdot302 - D)} - 151\cdot206$
12 D − 78·878	$\sqrt{D(3792\cdot710 - D)} - 157\cdot756$
12½ D − 82·154	$\sqrt{D(4114\cdot234 - D)} - 164\cdot308$
13 D − 85·428	$\sqrt{D(4448\cdot886 - D)} - 170\cdot856$
13½ D − 88·706	$\sqrt{D(4796\cdot663 - D)} - 177\cdot412$
14 D − 91·983	$\sqrt{D(5157\cdot562 - D)} - 183\cdot966$
14½ D − 95·258	$\sqrt{D(5531\cdot586 - D)} - 190\cdot516$
15 D − 98·535	$\sqrt{D(5918\cdot734 - D)} - 197\cdot070$
15½ D − 101·813	$\sqrt{D(6319\cdot002 - D)} - 203\cdot626$
16 D − 105·090	$\sqrt{D(6732\cdot398 - D)} - 210\cdot180$

XVIII.—POINTS AND

TABLE OF NUMBERS, RADII, CURVE-LEADS,

Gauge (G) = 3′ 0″ = 3′.

APPROXIMATE

$R = 6\,I^2 + 4 \cdot 5$ $L' = 6\,I + \frac{1 \cdot 5}{I}.$

Number. I.	Radius. R.	Curve-lead. L′.	Switch-lead. l′.	Lead. L.	
				′	″
5	154·485	30·297	9·494	20	9½
5½	185·988	33·270	10·418	22	10¼
6	220·491	36·249	11·344	24	10¾
6½	257·992	39·231	12·272	26	11½
7	298·493	42·213	13·200	29	0¼
7½	341·994	45·198	14·129	31	0¾
8	388·495	48·186	15·060	33	1½
8½	437·996	51·177	15·991	35	2¼
9	490·497	54·165	16·923	37	3
9½	545·997	57·159	17·855	39	3¾

CROSSINGS.

SWITCH-LEADS, AND LEADS; TURNOUTS AND CROSSOVERS.

Clearance (d) = $3\frac{1}{2}'' = 0'{\cdot}292$.

FORMULÆ.

$$l' = 1{\cdot}872\,I + \frac{0{\cdot}671}{I}. \qquad L = 4{\cdot}1281\,I + \frac{0{\cdot}813}{I}.$$

TURNOUTS AND CROSSOVERS.

Straight Intermediate Portion. S.	Curved Intermediate Portion. S.
$5\ D - 30{\cdot}297$	$\sqrt{D(611{\cdot}940 - D)} - 60{\cdot}594$
$5\frac{1}{2}\ D - 33{\cdot}270$	$\sqrt{D(737{\cdot}952 - D)} - 66{\cdot}540$
$6\ D - 36{\cdot}249$	$\sqrt{D(875{\cdot}964 - D)} - 72{\cdot}498$
$6\frac{1}{2}\ D - 39{\cdot}231$	$\sqrt{D(1025{\cdot}968 - D)} - 78{\cdot}462$
$7\ D - 42{\cdot}213$	$\sqrt{D(1187{\cdot}972 - D)} - 84{\cdot}426$
$7\frac{1}{2}\ D - 45{\cdot}198$	$\sqrt{D(1361{\cdot}976 - D)} - 90{\cdot}396$
$8\ D - 48{\cdot}186$	$\sqrt{D(1547{\cdot}980 - D)} - 96{\cdot}372$
$8\frac{1}{2}\ D - 51{\cdot}177$	$\sqrt{D(1745{\cdot}984 - D)} - 102{\cdot}354$
$9\ D - 54{\cdot}165$	$\sqrt{D(1955{\cdot}988 - D)} - 108{\cdot}330$
$9\frac{1}{2}\ D - 57{\cdot}159$	$\sqrt{D(2177{\cdot}988 - D)} - 114{\cdot}318$
$10\ D - 60{\cdot}150$	$\sqrt{D(2411{\cdot}988 - D)} - 120{\cdot}300$
$10\frac{1}{2}\ D - 63{\cdot}144$	$\sqrt{D(2657{\cdot}988 - D)} - 126{\cdot}288$
$11\ D - 66{\cdot}135$	$\sqrt{D(2915{\cdot}988 - D)} - 132{\cdot}270$
$11\frac{1}{2}\ D - 69{\cdot}129$	$\sqrt{D(3185{\cdot}988 - D)} - 138{\cdot}258$
$12\ D - 72{\cdot}126$	$\sqrt{D(3467{\cdot}988 - D)} - 144{\cdot}252$
$12\frac{1}{2}\ D - 75{\cdot}120$	$\sqrt{D(3761{\cdot}988 - D)} - 150{\cdot}240$
$13\ D - 78{\cdot}115$	$\sqrt{D(4067{\cdot}988 - D)} - 156{\cdot}230$
$13\frac{1}{2}\ D - 81{\cdot}111$	$\sqrt{D(4385{\cdot}988 - D)} - 162{\cdot}222$
$14\ D - 84{\cdot}107$	$\sqrt{D(4715{\cdot}988 - D)} - 168{\cdot}214$
$14\frac{1}{2}\ D - 87{\cdot}103$	$\sqrt{D(5057{\cdot}988 - D)} - 174{\cdot}206$
$15\ D - 90{\cdot}100$	$\sqrt{D(5411{\cdot}988 - D)} - 180{\cdot}200$
$15\frac{1}{2}\ D - 93{\cdot}097$	$\sqrt{D(5777{\cdot}988 - D)} - 186{\cdot}194$
$16\ D - 96{\cdot}094$	$\sqrt{D(6155{\cdot}988 - D)} - 192{\cdot}188$

—POINTS AND CROSSINGS.

LEADS, SWITCH-LEADS, AND LEADS; TURNOUTS AND CROSSOVERS.

Clearance (d) = $2\frac{3}{4}''$ = $0'\cdot229$.

APPROXIMATE FORMULÆ.

$\frac{1\cdot25}{I}$. $l' = 1\cdot5134\,I + \frac{0\cdot54}{I}$. $L = 3\cdot4868\,I + \frac{0\cdot69}{I}$.

h-lead, ′.	Lead. L.	Turnouts and Crossovers.	
		Straight Intermediate Portion. S.	Curved Intermediate Portion. S.
	′ ″		
675	17 $6\frac{3}{4}$	$5\ D - 25\cdot247$	$\sqrt{D\,(509\cdot952 - D)} - 50\cdot494$
422	19 $3\frac{3}{4}$	$5\frac{1}{2}\ D - 27\cdot725$	$\sqrt{D\,(614\cdot960 - D)} - 55\cdot450$
170	21 $0\frac{1}{2}$	$6\ D - 30\ 207$	$\sqrt{D\,(729\cdot964 - D)} - 60\cdot414$
920	22 $9\frac{1}{4}$	$6\frac{1}{2}\ D - 32\cdot691$	$\sqrt{D\,(854\cdot972 - D)} - 65\cdot382$
671	24 6	$7\ D - 35\cdot178$	$\sqrt{D\,(989\cdot976 - D)} - 70\cdot356$
423	26 3	$7\frac{1}{2}\ D - 37\cdot666$	$\sqrt{D\,(1134\cdot976 - D)} - 75\cdot332$
175	27 $11\frac{3}{4}$	$8\ D - 40\cdot156$	$\sqrt{D\,(1289\cdot980 - D)} - 80\cdot312$
928	29 $8\frac{1}{2}$	$8\frac{1}{2}\ D - 42\cdot647$	$\sqrt{D\,(1454\cdot984 - D)} - 85\cdot294$
681	31 $5\frac{1}{2}$	$9\ D - 45\cdot138$	$\sqrt{D\,(1629\cdot984 - D)} - 90\cdot276$
434	33 $2\frac{1}{4}$	$9\frac{1}{2}\ D - 47\cdot631$	$\sqrt{D\,(1814\cdot988 - D)} - 95\cdot262$
188	34 $11\frac{1}{4}$	$10\ D - 50\cdot125$	$\sqrt{D\,(2009\cdot988 - D)} - 100\cdot250$

XX.

INDIAN STATE RAILWAYS, 5′ 6″ GAUGE.

POINTS AND CROSSINGS.

Number. I.	Angle. α.	Radius. R.	Curve-lead. L′.	Switch-lead. l′.	Lead. L.	Remarks.
	° ′ ″		′ ″	′ ″	′ ″	
5·2671	10 45 0	313·48	58 6	14 11	43 7	Old standard crossings, still in use.
7·3479	7 45 0	602·14	81 3	20 8	60 7	
9·9310	5 45 0	1093·11	109 6	27 10	81 8	
6	9 27 44	404·23	66 5	16 10	49 7	New standard crossings.
8½	6 42 35	802·99	93 10	23 10	70 0	
12	4 45 49	1592·24	132 3	33 7	98 0	

TURNOUTS AND CROSSOVERS.

Crossing.	Straight Intermediate Portion (Figures 19 and 20). S.					
	D = 13½.	D = 14.	D = 15.	D = 16.	D = 18.	D = 20.
° ′	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″
10 45	12 8	15 3	20 7	25 10	36 4	46 11
7 45	18 0	21 8	29 0	36 4	51 1	65 9
5 45	24 7	29 6	39 5	49 4	69 3	89 1
1 in 6	14 7	17 7	23 7	29 7	41 7	53 7
1 in 8½	20 11	25 2	33 8	42 2	59 2	76 2
1 in 12	29 9	35 9	47 9	59 9	83 9	107 9
	Curved Intermediate Portion (Figures 21 and 22).					
10 45	11 10	14 2	18 9	23 1	31 6	39 5
7 45	15 11	19 9	25 7	31 8	43 6	54 7
5 45	23 3	27 8	36 4	44 8	60 7	75 8
1 in 6	13 9	16 5	21 8	26 8	36 3	45 3
1 in 8½	19 9	23 7	30 11	38 1	51 8	64 7
1 in 12	28 2	33 6	43 11	54 0	73 4	91 6

XXI.

INDIAN STATE RAILWAYS, 3′ 3⅜″ GAUGE.

Points and Crossings.

Number. I.	Angle. a.	Radius. R.	Curve-lead. L′.	Switch-lead. l′.	Lead. L.	Remarks.
	° ′ ″		′ ″	′ ″	′ ″	
5·1446	11 0 0	178·50	34 1	10 5	23 8	Old standard crossings, still in use.
7·3479	7 45 0	359·19	48 5	14 8	33 9	
10·3854	5 30 0	712·65	68 4	20 9	47 7	
6¾	8 25 38	303·86	44 6	13 6	31 0	Later standard crossings.
9½	6 0 32	597·12	62 6	19 0	43 6	
12	4 45 49	949·82	78 11	24 0	54 11	
6	9 27 44	241·14	39 8	12 1	27 7	Standard crossings of 1892.
8½	6 42 35	479·00	56 0	17 0	39 0	

Turnouts and Crossovers.

Crossing.	Straight Intermediate Portion (Figures 19 and 20). S.					
	D = 13.	D = 14.	D = 15.	D = 16.	D = 18.	D = 20.
° ′	′ ″	′ ″	′ ″	′ ″	′ ″	′ ″

XXII.

Selected from Enclosure to P. W. Dept. Circular No. 5 *Railway of* 1892.

CERTAIN STANDARD DIMENSIONS TO BE OBSERVED ON RAILWAYS IN INDIA.

(For the information of Permanent-way Inspectors.)

I.—FORMATION.

	GAUGE.	
	5′ 6″.	Metre.
SINGLE LINE—		
Minimum width of formation—		
(1) In embankment	20 ft. 0 in.	16 ft. 0 in.
(2) In cutting (excluding side drains) ..	18 ft. 0 in.	14 ft. 0 in.
DOUBLE LINE—		
Minimum width of formation—		
(3) In embankment	34 ft. 0 in.	28 ft. 0 in.
(4) In cutting (excluding side drains) ..	32 ft. 0 in.	26 ft. 0 in.
(5) Standard distance, centre to centre of tracks (out of stations)	14 ft. 0 in.	12 ft. 0 in.
CURVES—		
Maximum angle of curvature—		
(6) In ordinary country	3° 0′ (rad. = 1910 ft.)	5° 0′ (rad. = 1146 ft.)
(7) In difficult country	6° 0′ (rad. = 955 ft.)	10° 0′ (rad. = 573 ft.)
N.B.—The angle of curvature is taken as the angle at the centre subtended by an arc of 101 feet in length. Thus the radius for a one degree curve is 5729·578 feet. The maximum angles of curvature given above do not apply to curves in station yards.		

II.—BALLAST AND PERMANENT WAY.

BALLAST—		
(8) Minimum width of ballast at rail level	11 ft. 0 in.	7 ft. 6 in.
(9) Minimum depth of ballast below sleepers	8 inches	6 inches
N.B.—These minimum dimensions may be relaxed in the case of a line being opened to traffic before the banks have settled.		

II.—BALLAST AND PERMANENT WAY—*continued.*

	GAUGE.	
	5′ 6″.	Metre.
SLEEPERS—		
Minimum dimensions for timber cross sleepers—		
(10) Length	8 ft. 11 in.	6 ft. 0 in.
(11) Breadth	9 inches	7 inches
(12) Depth	5 inches	4½ inches
(13) Minimum area in cross section ..	50 sq. in.	36 sq. in.
(14) Minimum number of cross sleepers per mile	1760	1936
N.B.—On bridges where the cross sleepers rest directly on longitudinal girders the sleepers are to be spaced not more than 2 ft. 6 in. apart, centre to centre, and are to be not less than 6 inches deep, exclusive of any notching which may be required on the under side to allow for the cover-plates, camber, &c.		
RAILS—		
(15) Maximum clearance of guard rail for points and crossings	1⅞ inch	1¾ inch
(16) Minimum clearance of guard rail for points and crossings	1¾ inch	1⅝ inch
(17) Minimum clearance of guard rail for curves and level crossings..	2 inches	2 inches
N.B.—The *maximum* clearance for curves and level crossings will vary according to the radius of curve.		
(18) Minimum depth of space for wheel flange, from rail level	1½ inch	1⅜ inch

III.—Fixed Structures (in Stations)—*continued.*

	Gauge.	
	5′ 6″.	Metre.
Buildings— (24) Minimum horizontal distance from centre of track to any structure in the vicinity of a *passenger* platform (but not *on* a platform), within a height of 12 feet from rail level	9 ft. 0 in.	10 ft. 1 in.
N.B.—This rule does not apply to point levers between tracks or to water cranes. (*See items Nos.* 38 *and* 45.) For extra allowance on sharp curves see item No. 19.		
(25) Minimum horizontal distance from centre of track to any structure not in the vicinity of a *passenger* platform, from platform level, if any, or from 1 foot above rail level, if there be no platform, to a height of 11 ft. 6 in. above rail level	7 ft. 0 in.	7 ft. 0 in.
N.B.—Under the last entry coal or any material stacked by the side of any track is to be considered a structure in the sense in which the word is here used. A projecting overhanging roof is permissible in the case of a goods shed on a siding, if such roof extends over the centre of the track at a height of not less than 14 ft. 6 in. above rail level; or if it does not infringe the outline of the figure for minimum fixed structure out of stations. For extra allowance on sharp curves see item No. 19.		

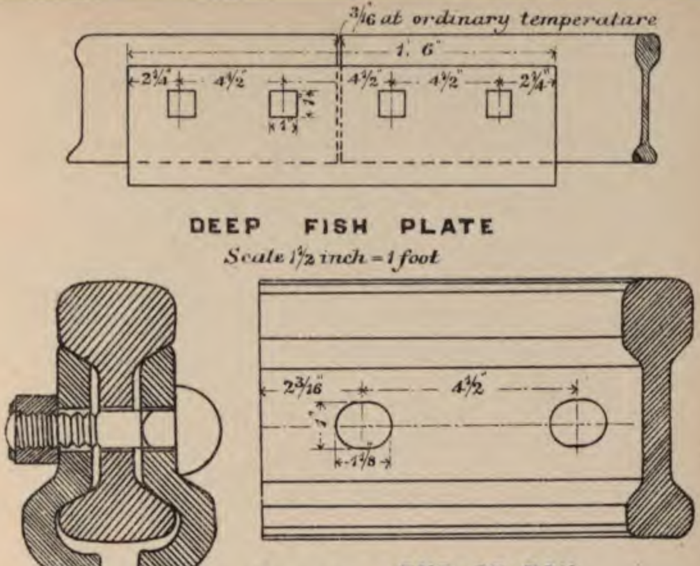
IV.—Fixed Structures (Out of Stations).

Buildings, Etc.— (30) Minimum horizontal distance from centre of track to any structure out of stations, from 1 foot above rail level to a height of 11 ft. 6 in. above rail level..	7 ft. 0 in.	7 ft. 0 in.
N.B.—Under this entry any material stacked by the side of the line is to be considered a structure in the sense in which the word is here used. For extra allowance on sharp curves see item No. 19.		

V.—STATION YARDS.

	GAUGE.	
	5′ 6″.	Metre.
SPACING OF TRACKS—		
(34) Minimum distance, centre to centre of tracks	15 ft. 6 in.	..
Track nearest platform to next track	..	16 ft. 7 in.
All other tracks in station yard ..	..	15 ft. 6 in.
POINTS AND CROSSINGS—		
The following (items Nos. 35, 36 and 37) are recommended for general use, and are to be adopted on all State railways :—		
(35) *Minimum radius of curve*	800 *feet*	478 *feet*
(36) *Standard crossings*	1-*in*-6 1-*in*-8½ 1-*in*-12	1-*in*-6 1-*in*-8½ 1-*in*-12
(37) *Standard lengths for tongue rails* ..	12 *ft.* 0 *in.* 15 *ft.* 0 *in.*	9 *ft.* 0 *in.* 12 *ft.* 0 *in.*
(38) Minimum horizontal distance from centre of track to point handle, indicator, or any part of point apparatus above rail level ..	7 ft. 0 in.	7 ft. 0 in.

N.B.—A point handle may not, in any position, be within 7 feet of the centre line of nearest track; a



DEEP FISH PLATE

Scale 1½ inch = 1 foot

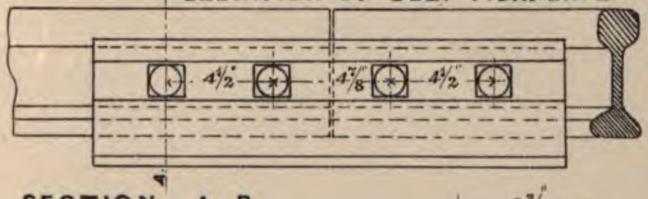
SECTION

Fig. 2

END OF RAIL

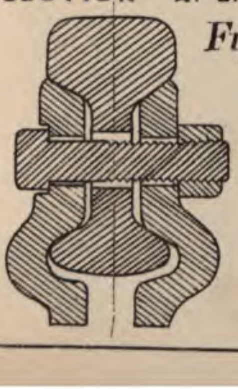
Scale ¼ Full Size

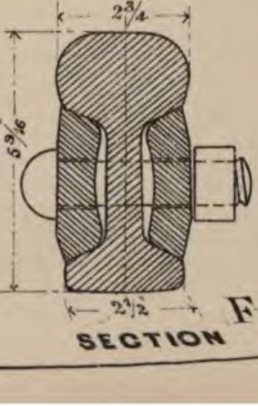
ELEVATION OF DEEP FISHPLATE



SECTION A. B.

Fig. 3

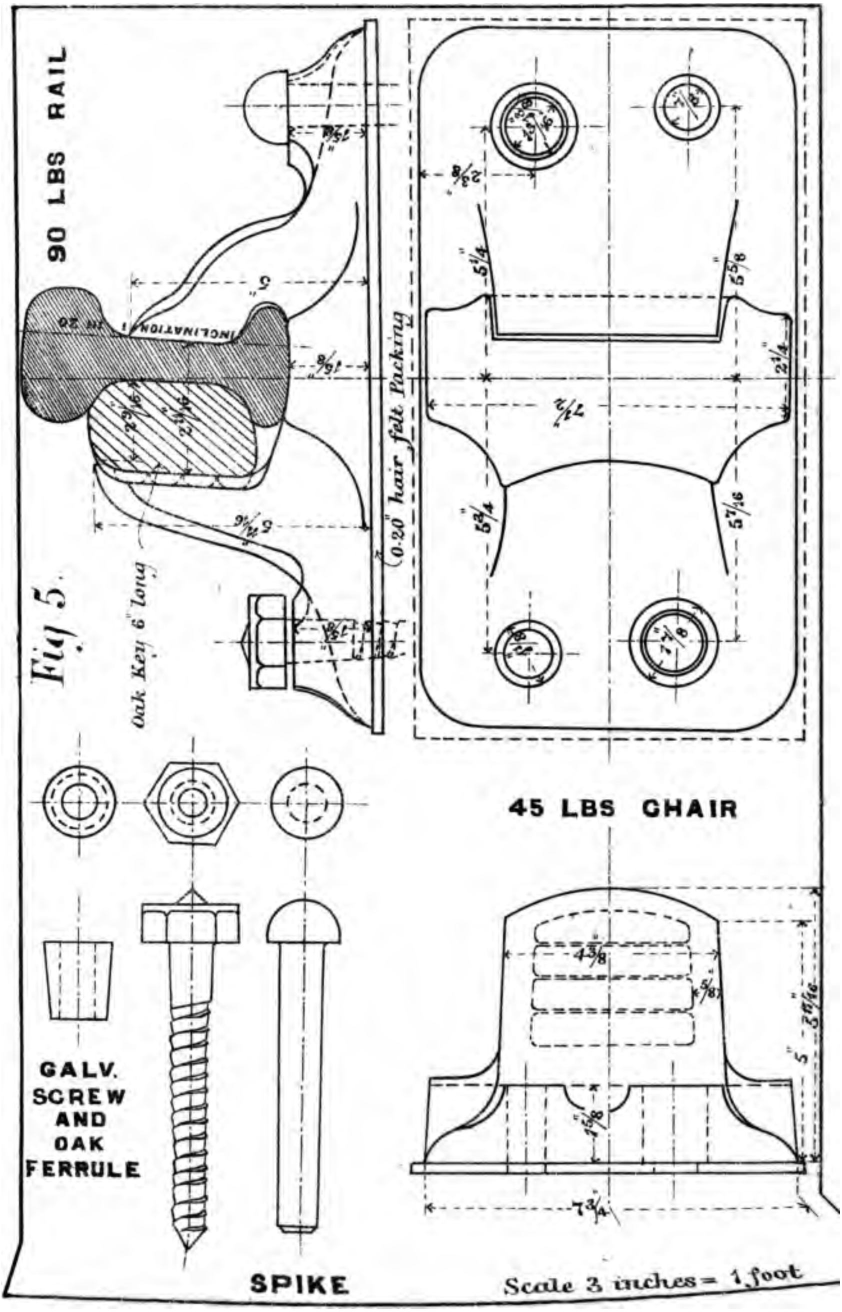




SECTION

Fig.

Fig 5.



Scale 3 inches = 1 foot

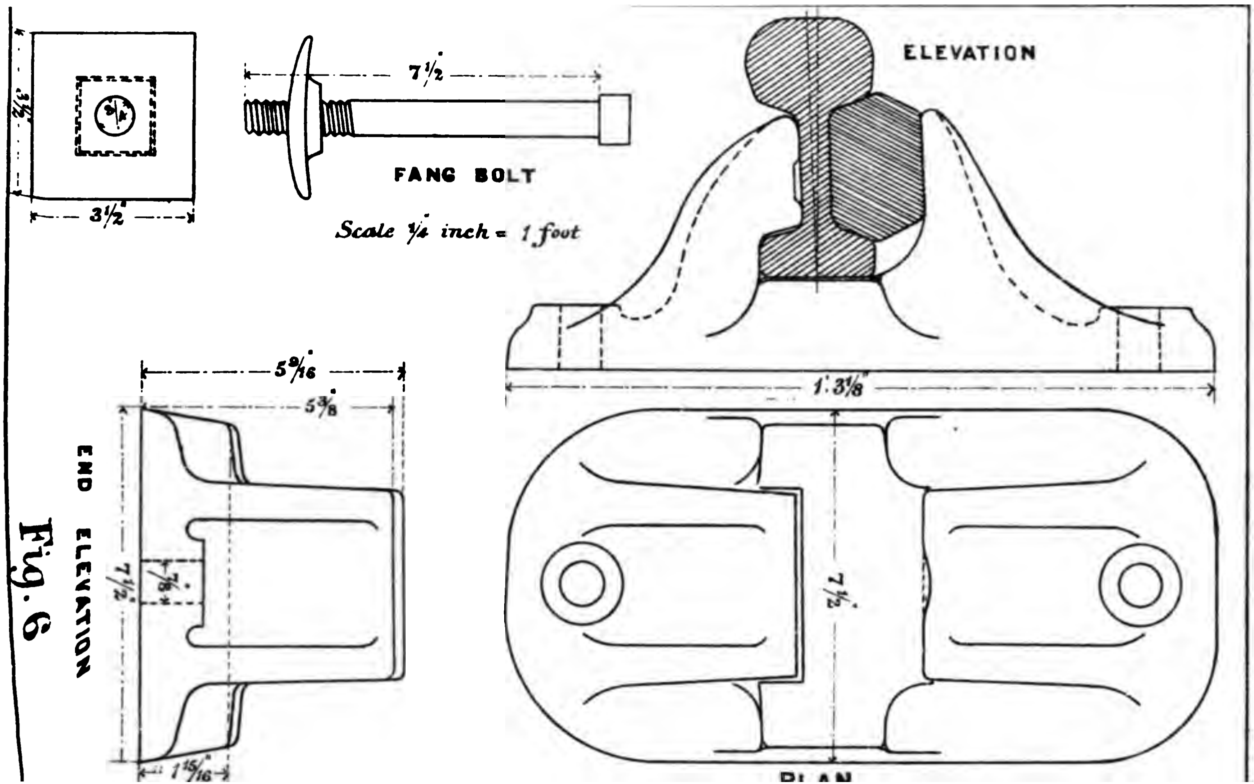

ELEVATION
1' 3⅛"
7½"
PLAN
7½"
FANG BOLT
Scale ¼" inch = 1 foot
3½"
3½"
5 9/16"
5⅜"
7½"
⅞"
1 15/16"
END ELEVATION

Fig. 6

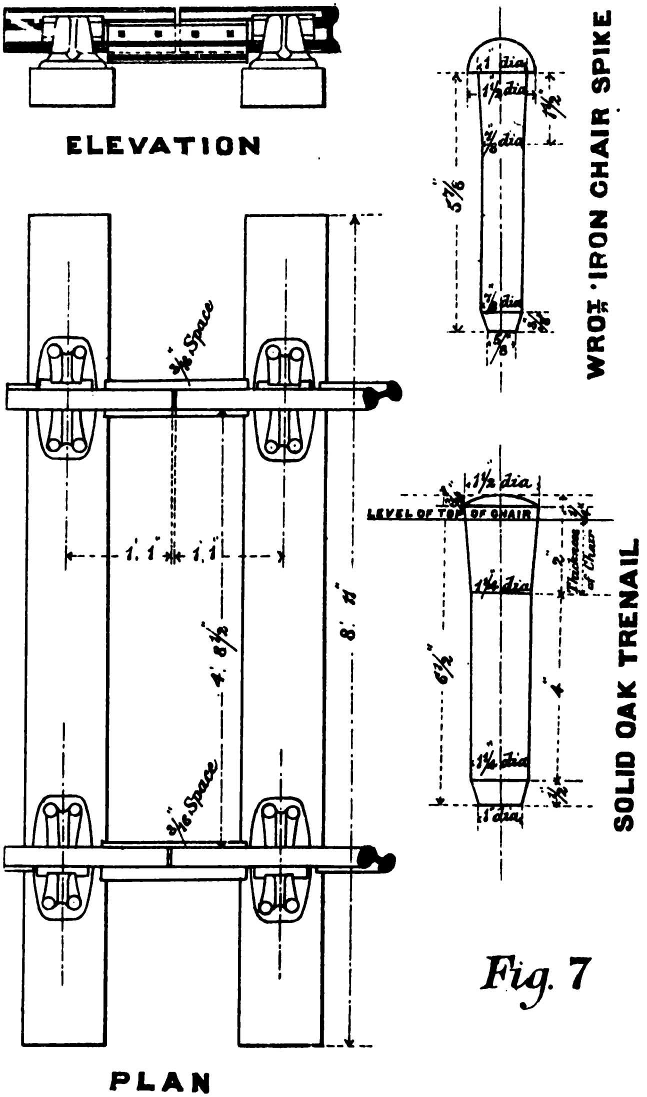
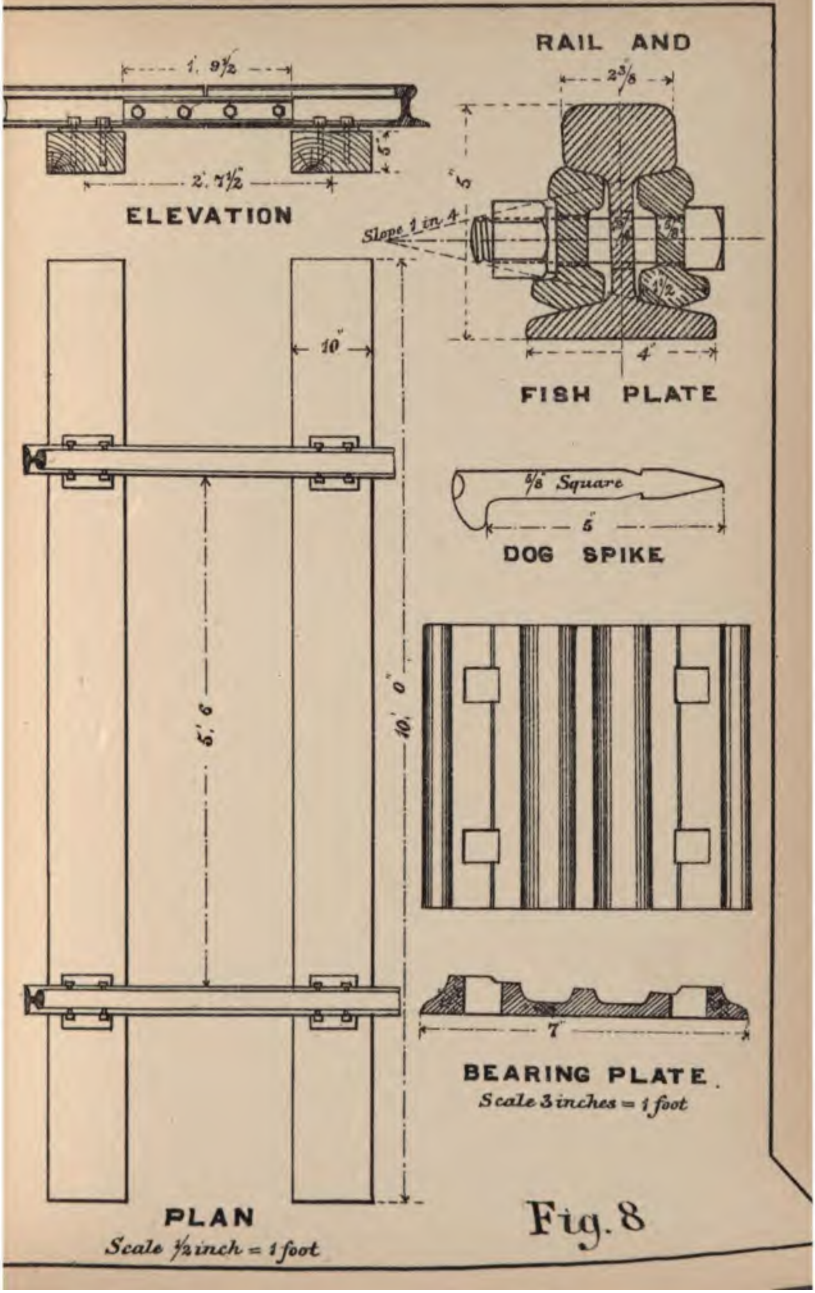

ELEVATION
3/16" Space
1' 1"
1' 1"
4' 8½"
8' 11"
PLAN
1 dia
1½ dia
1½"
⅞ dia
5⅞"
⅞ dia
⅝"
WROᵀ IRON CHAIR SPIKE
1½ dia
LEVEL OF TOP OF CHAIR
½"
2" Thickness of Chair
1¼ dia
6½"
4"
1¼ dia
½"
1 dia
SOLID OAK TRENAIL

Fig. 7



ELEVATION

RAIL AND FISH PLATE

DOG SPIKE

BEARING PLATE.
Scale 3 inches = 1 foot

PLAN
Scale ½ inch = 1 foot

Fig. 8

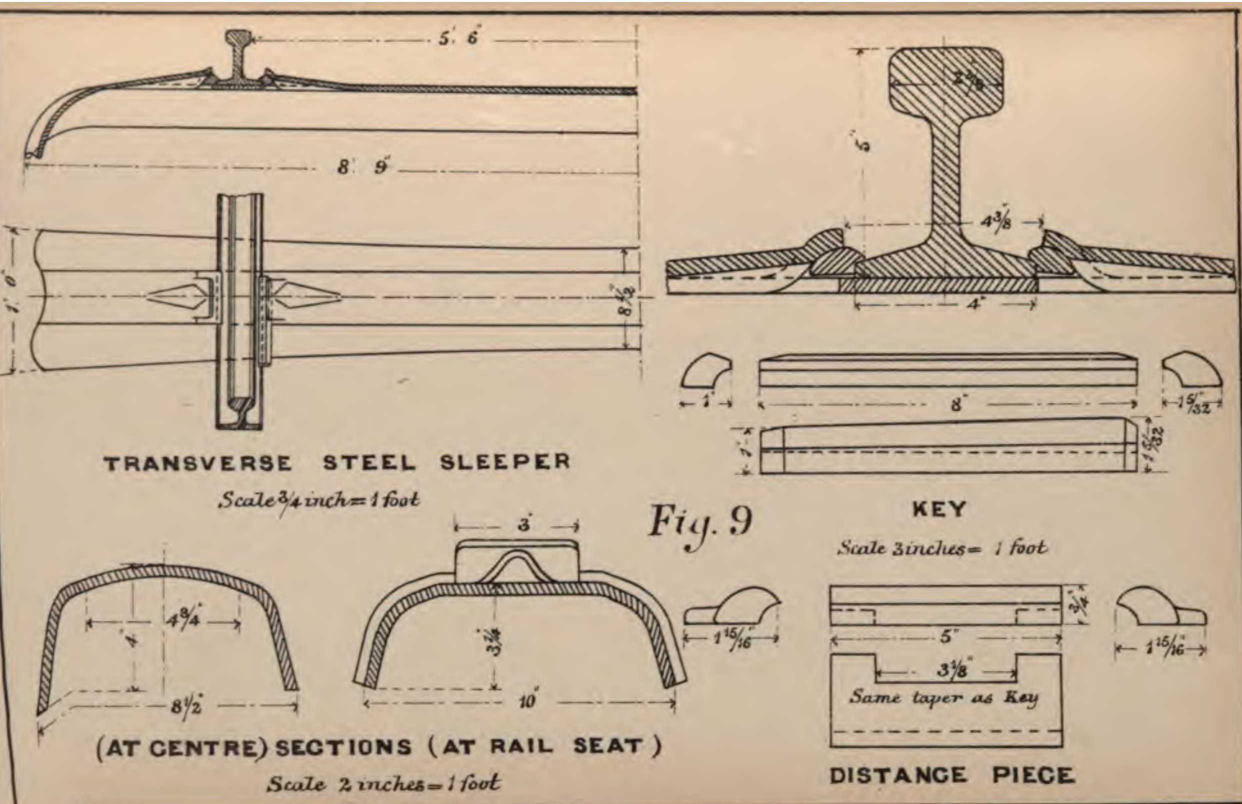


Fig. 9

TRANSVERSE STEEL SLEEPER

Scale 3/4 inch = 1 foot

KEY

Scale 3 inches = 1 foot

(AT CENTRE) SECTIONS (AT RAIL SEAT)

Scale 2 inches = 1 foot

DISTANCE PIECE

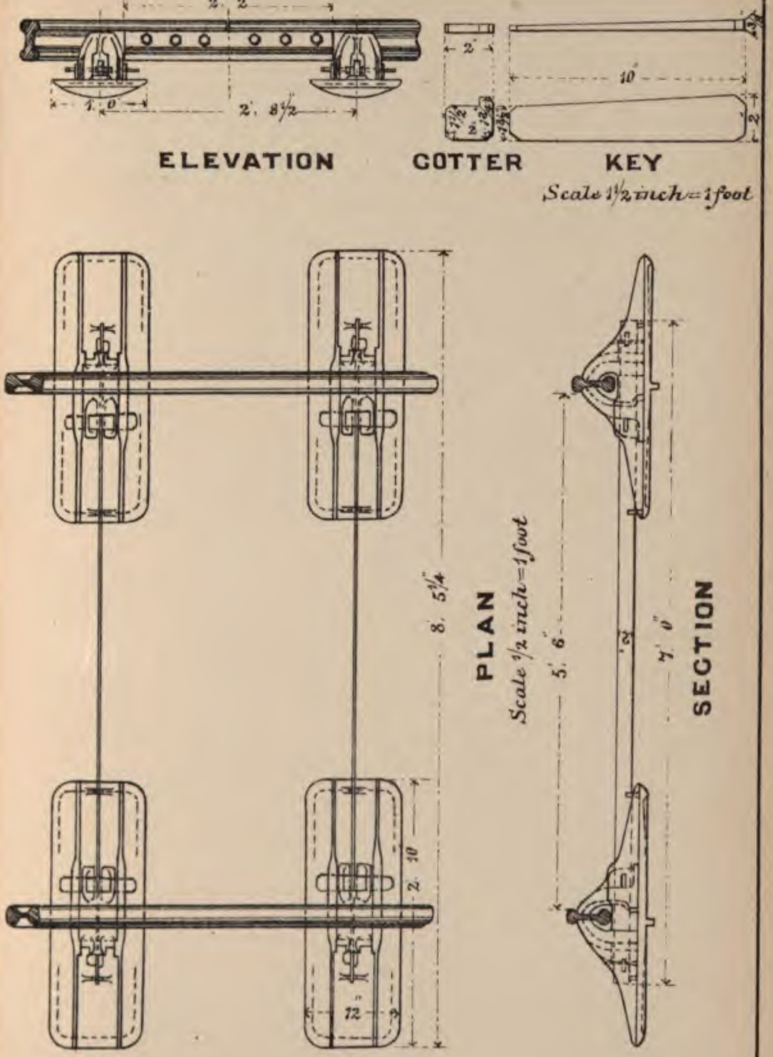
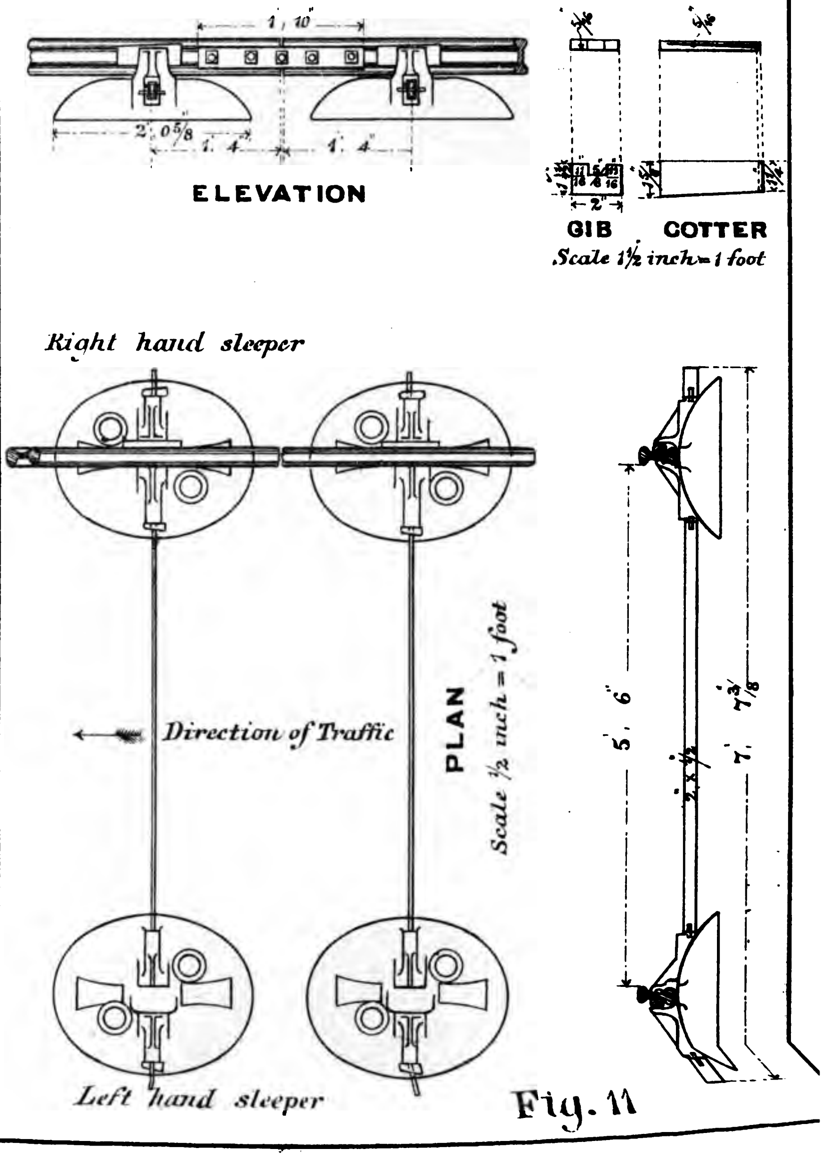

2' 2"
1' 0"
2' 8½"
ELEVATION
2"
COTTER
10"
2
KEY
Scale 1½ inch = 1 foot
8' 5¼"
PLAN
Scale ½ inch = 1 foot
5' 6"
7' 0"
SECTION
2' 10"
12"

Fig. 10



ELEVATION

GIB **COTTER**

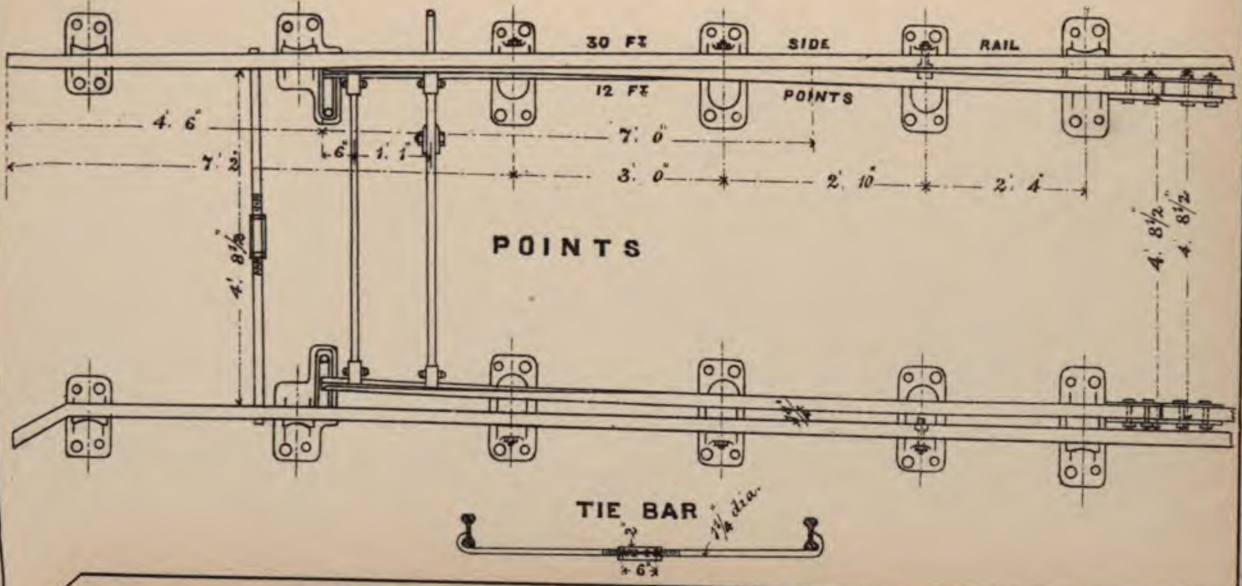
Scale 1½ inch = 1 foot

PLAN

Scale ½ inch = 1 foot

Fig. 11

Fig. 12


30 FT SIDE RAIL
12 FT POINTS
4' 6"
7' 2"
7' 0"
6"
1' 1"
3' 0"
2' 10"
2' 4"
4' 8½"
4' 8½"
4' 8½"
POINTS
TIE BAR
2"
1¼" dia.
6"

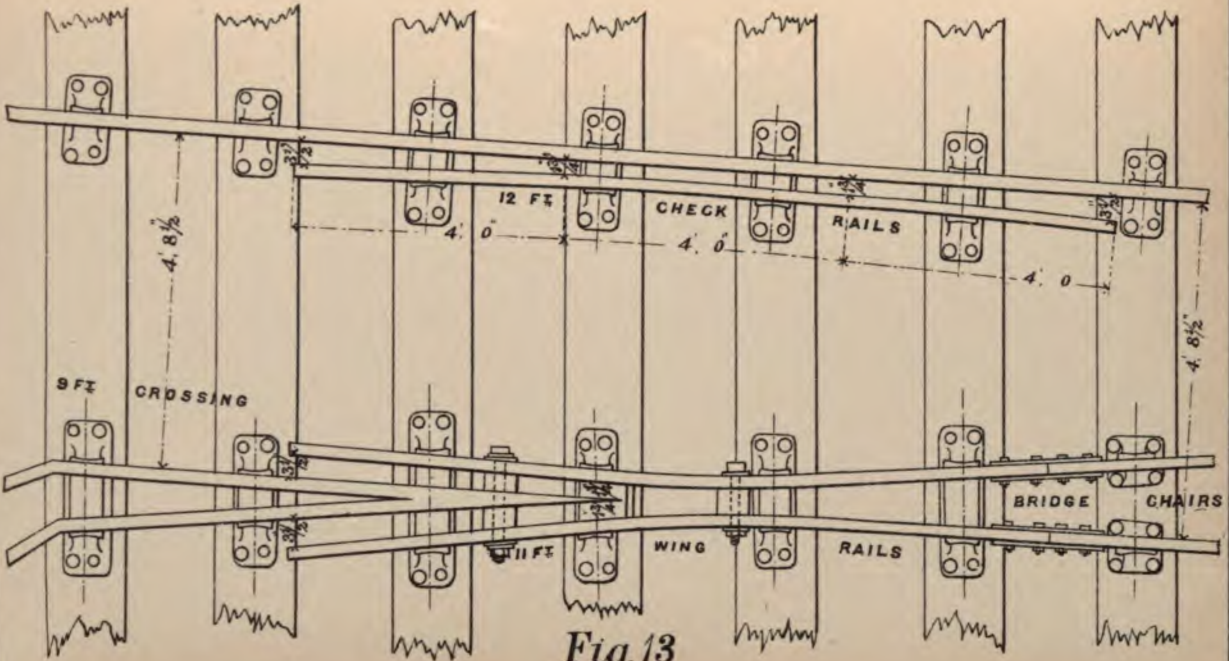
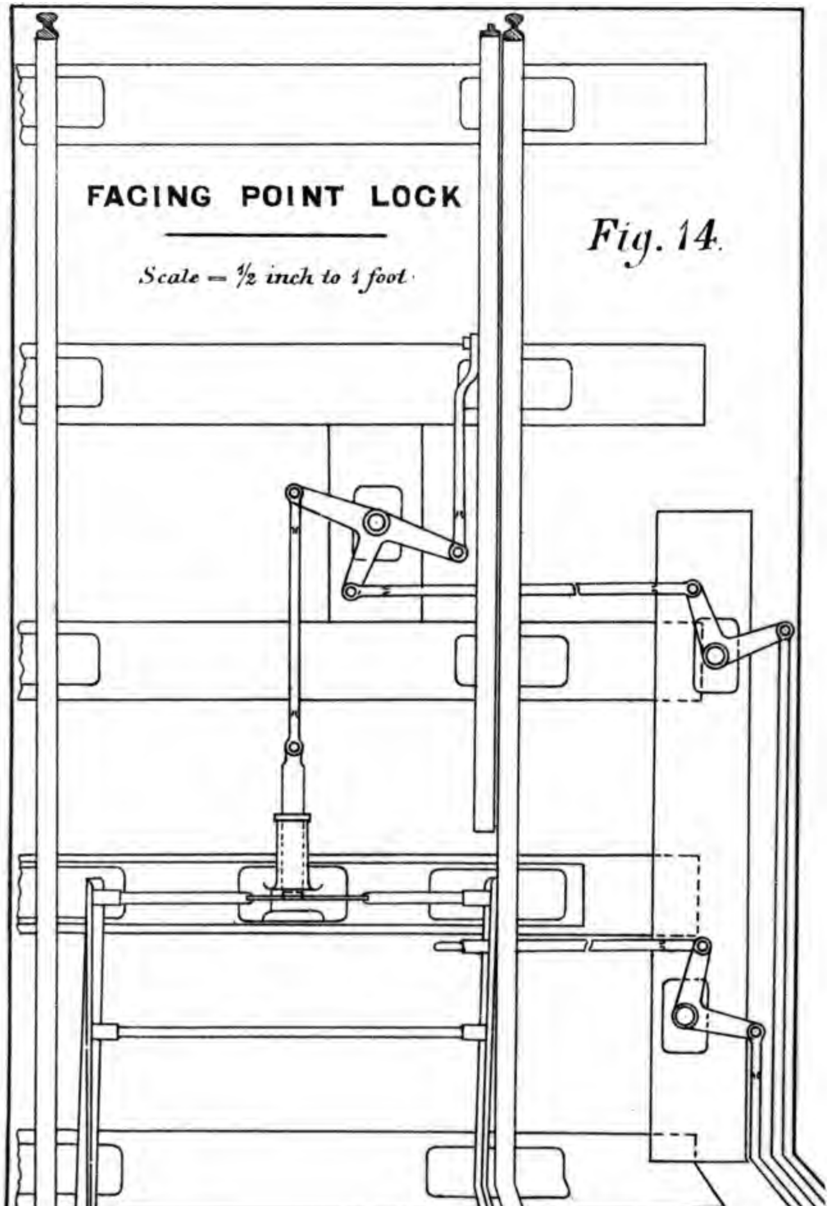

12 FT
CHECK
RAILS
4' 0"
4' 0"
4' 0
4' 8½"
4' 8½"
9 FT
CROSSING
11 FT
WING
RAILS
BRIDGE
CHAIRS
3½"
3½"

Fig. 13



FACING POINT LOCK

Scale = ½ inch to 1 foot.

Fig. 14.

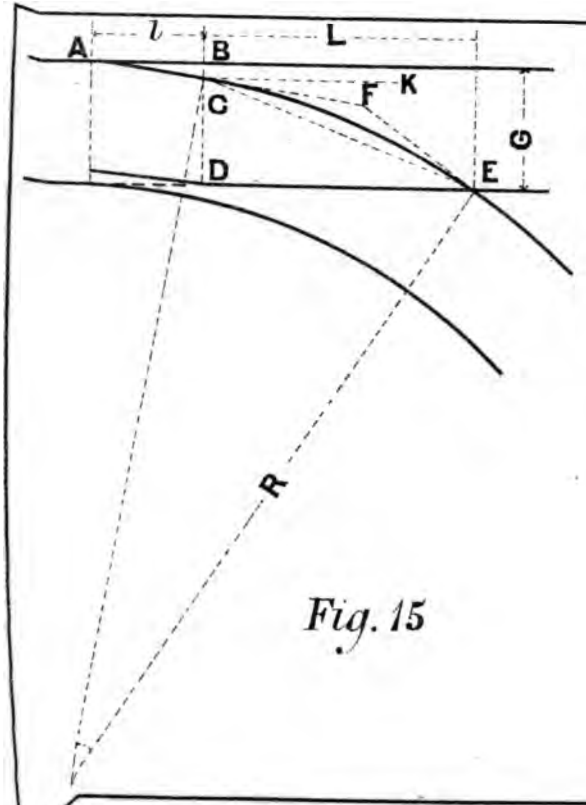


Fig. 15

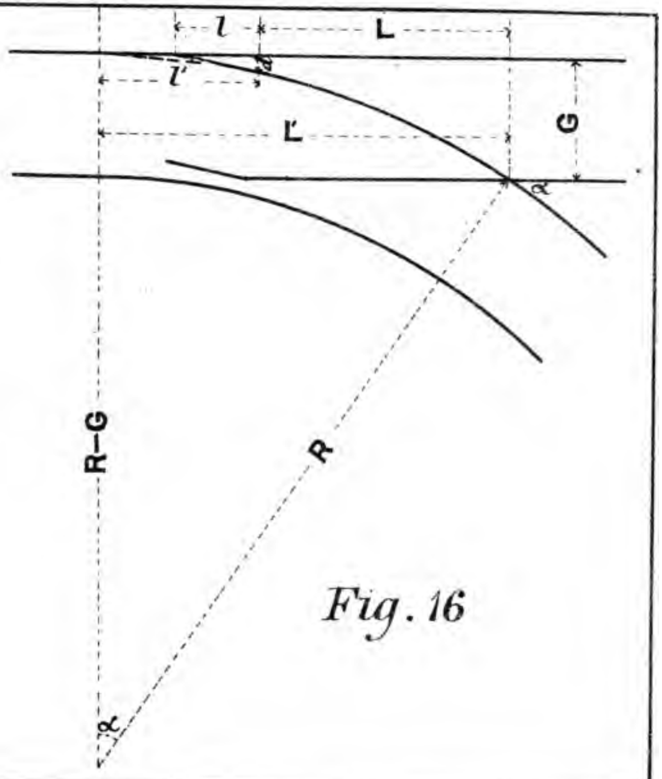


Fig. 16

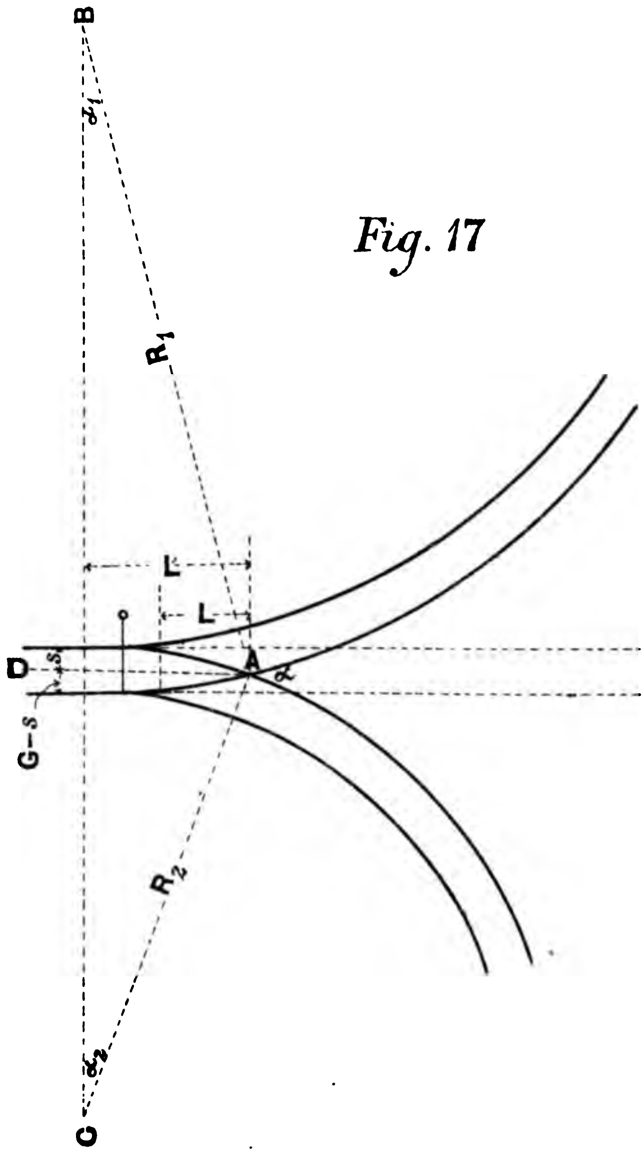


Fig. 17

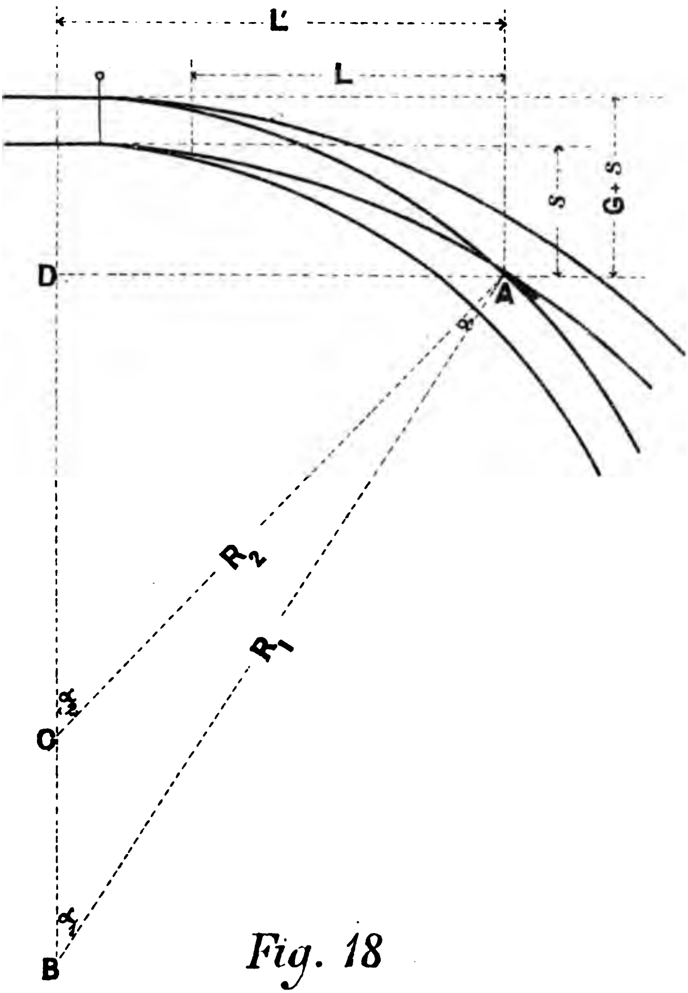


Fig. 18

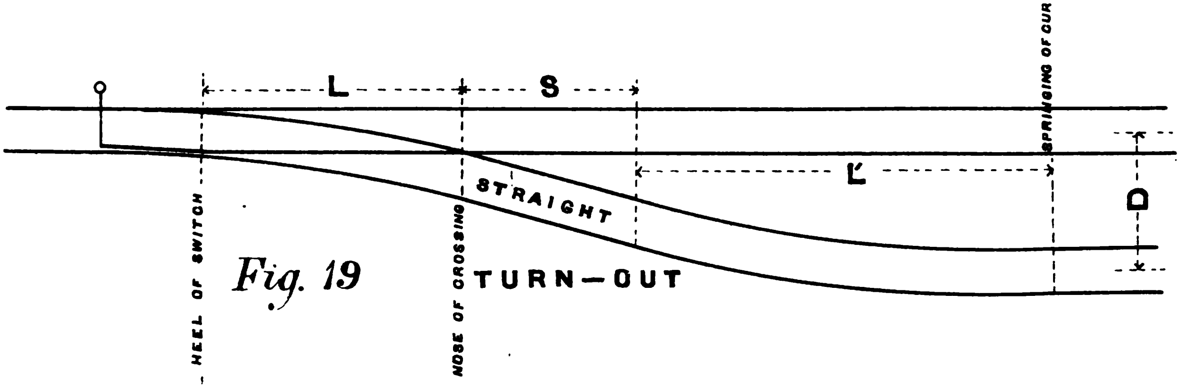

L
S
L′
D
STRAIGHT
TURN—OUT
HEEL OF SWITCH
NOSE OF CROSSING
SPRINGING OF CUR

Fig. 19

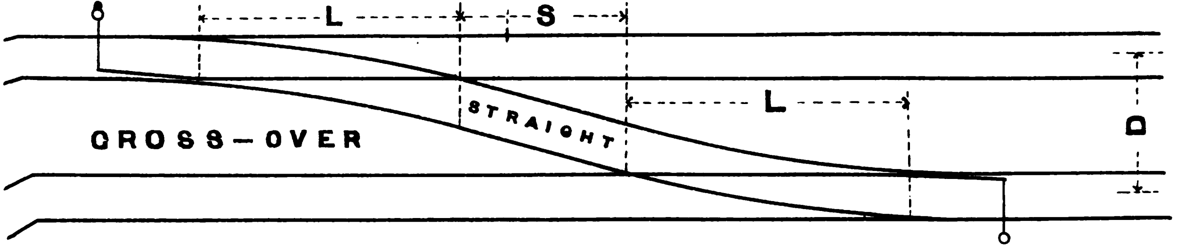
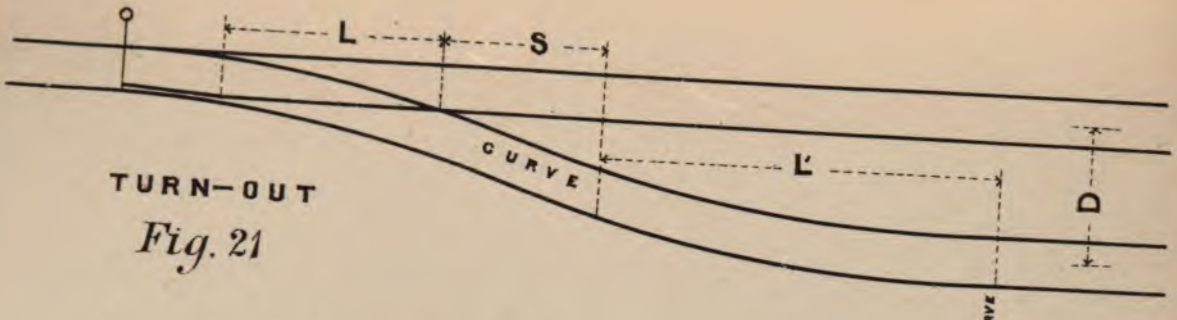
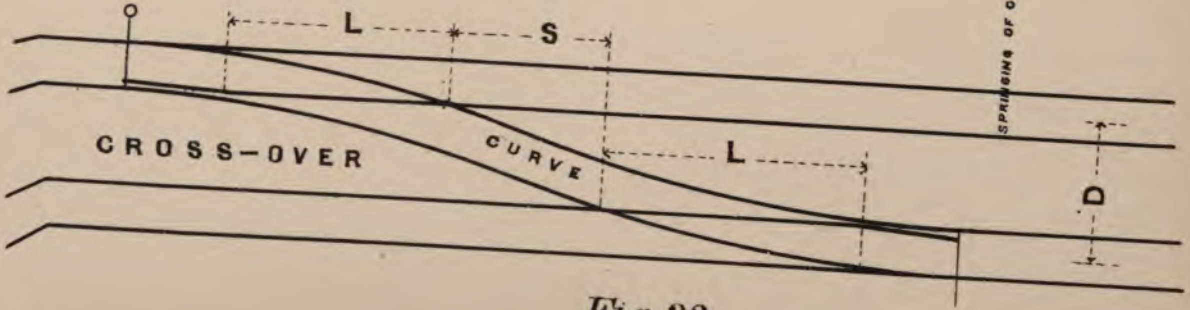

L
S
L
D
STRAIGHT
CROSS—OVER

Fig. 20



TURN-OUT

Fig. 21



CROSS-OVER

Fig. 22

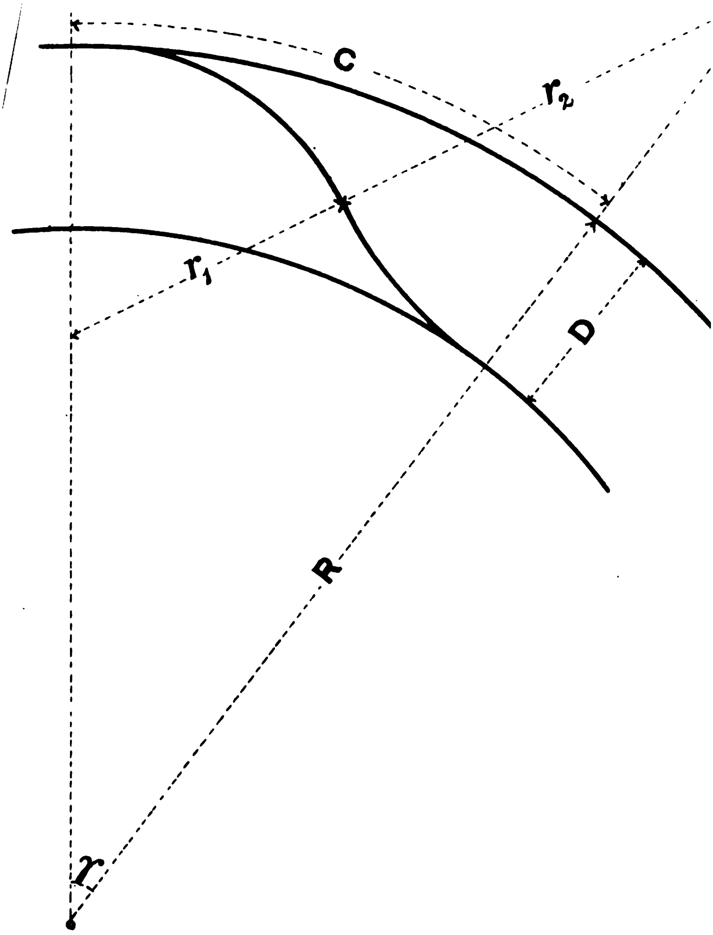


Fig. 23

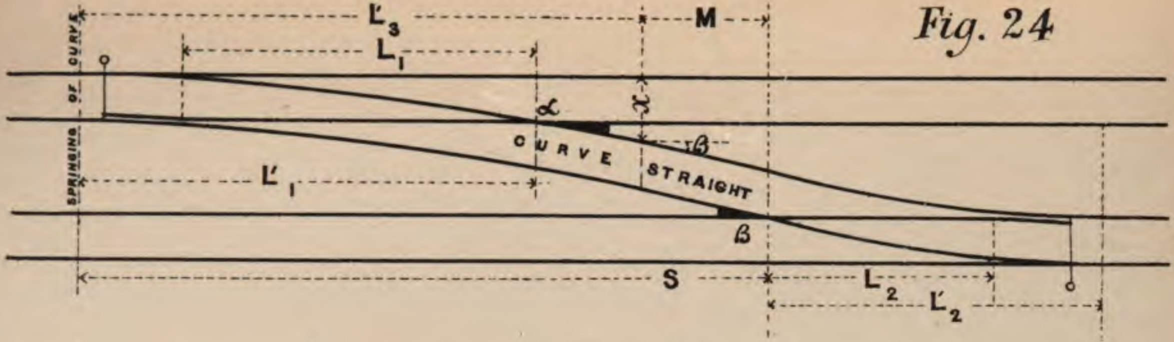

L'3
M
L1
SPRINGING OF CURVE
α
x
β
CURVE
STRAIGHT
L'1
β
S
L2
L'2

Fig. 24

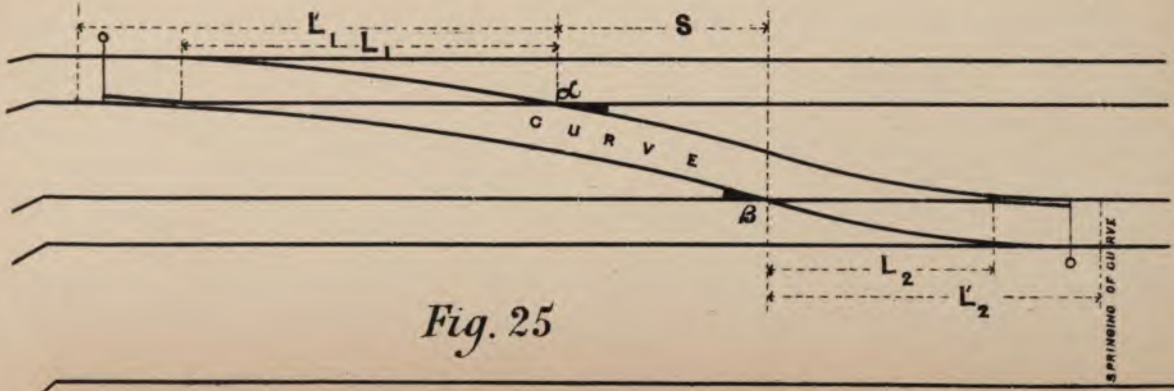

L'1
L1
S
α
CURVE
β
L2
L'2
SPRINGING OF CURVE

Fig. 25

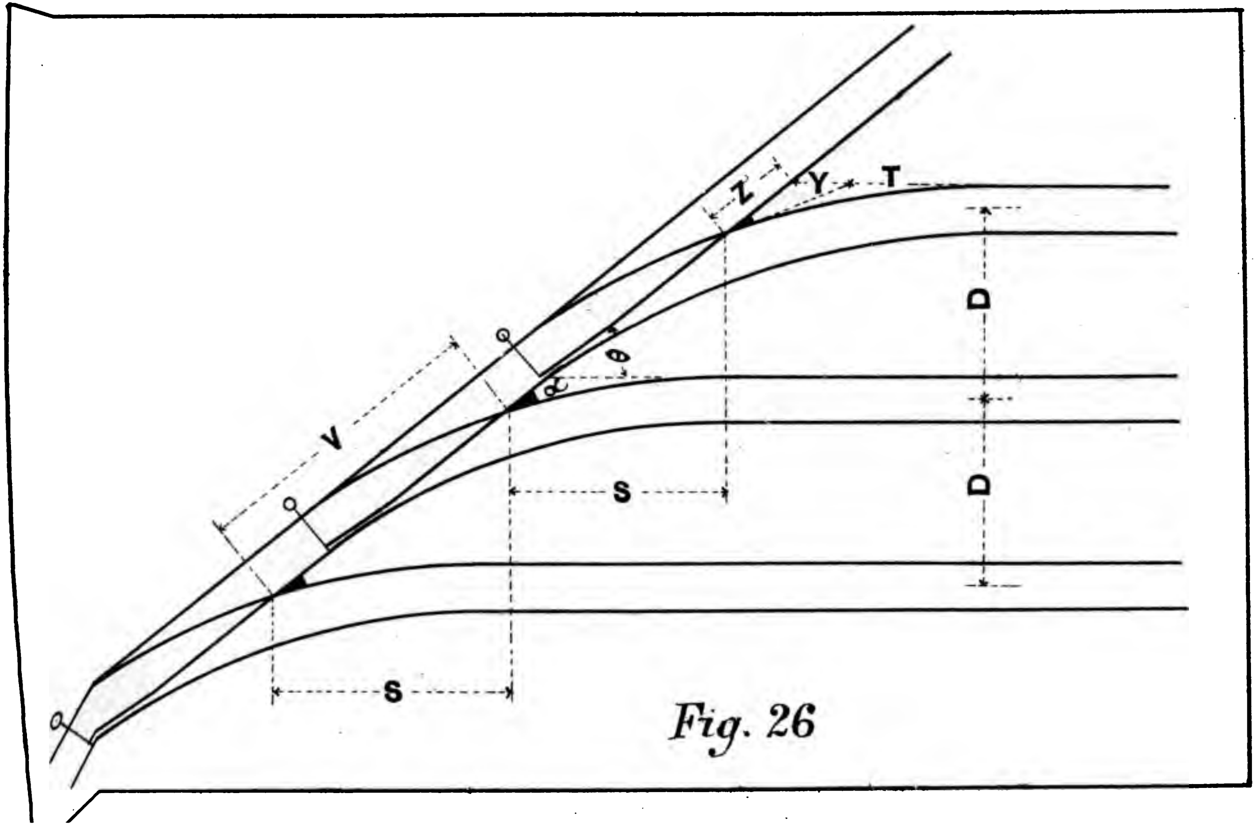


Fig. 26

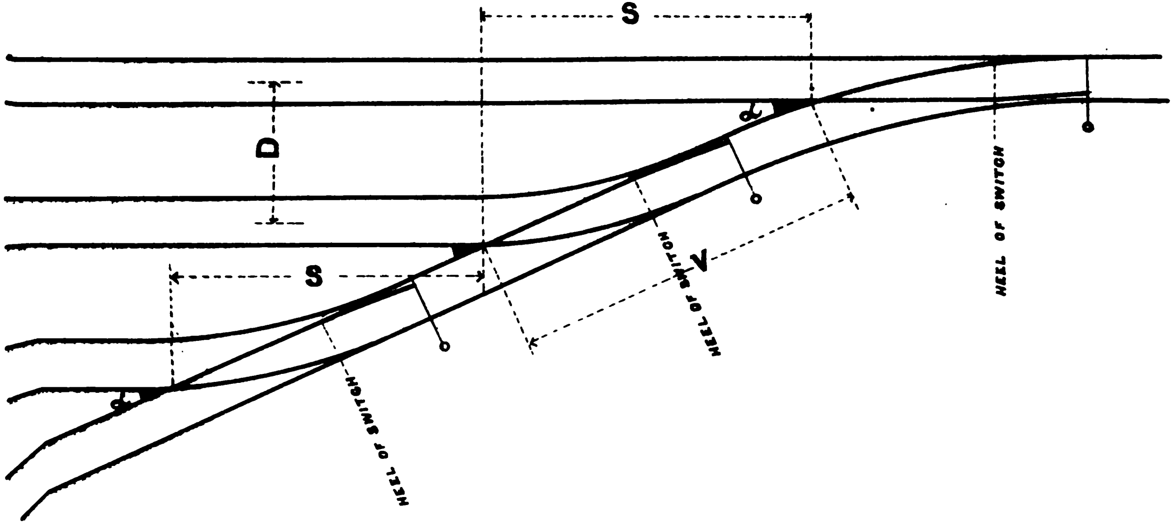


Fig. 27

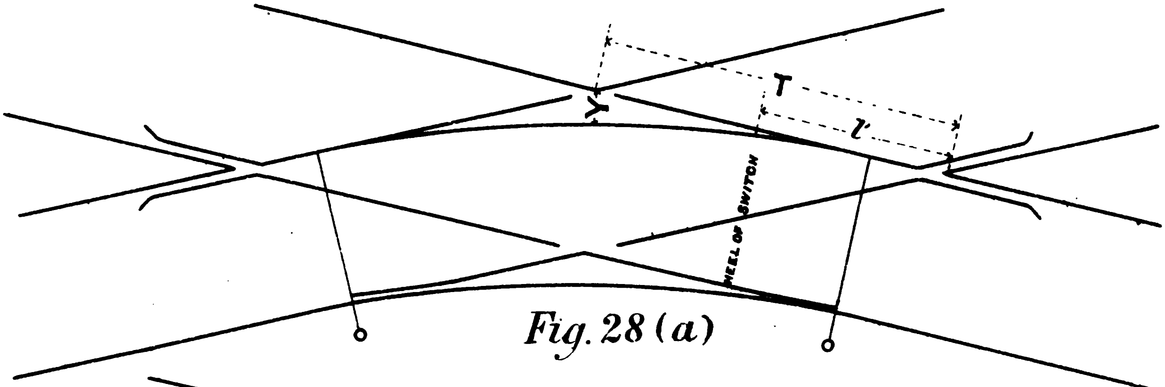


Fig. 28 (a)

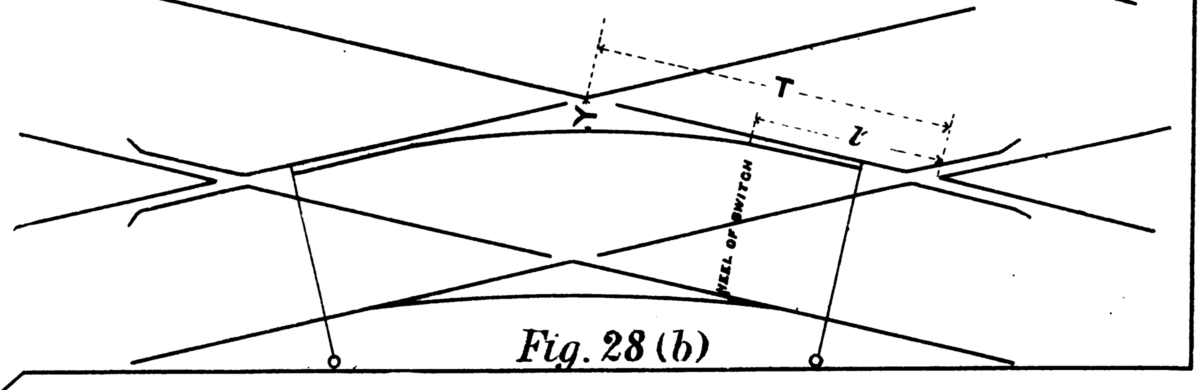


Fig. 28 (b)

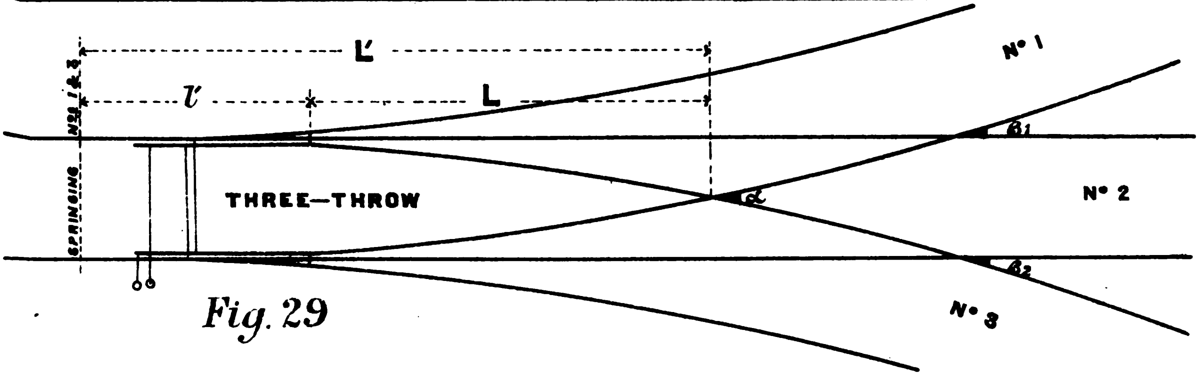

L′
l′
L
N° 1
N° 2
N° 3
β1
β2
α
THREE—THROW
SPRINGING
NOS 1 & 3

Fig. 29

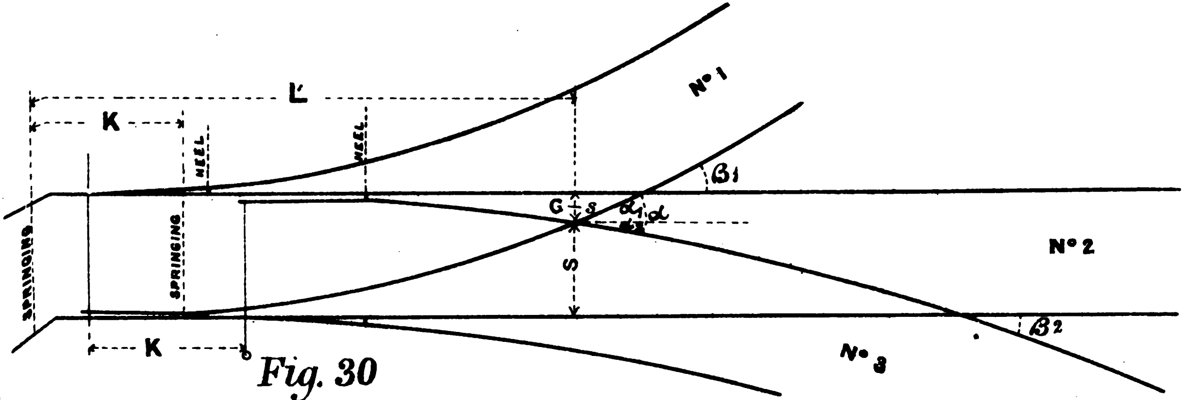
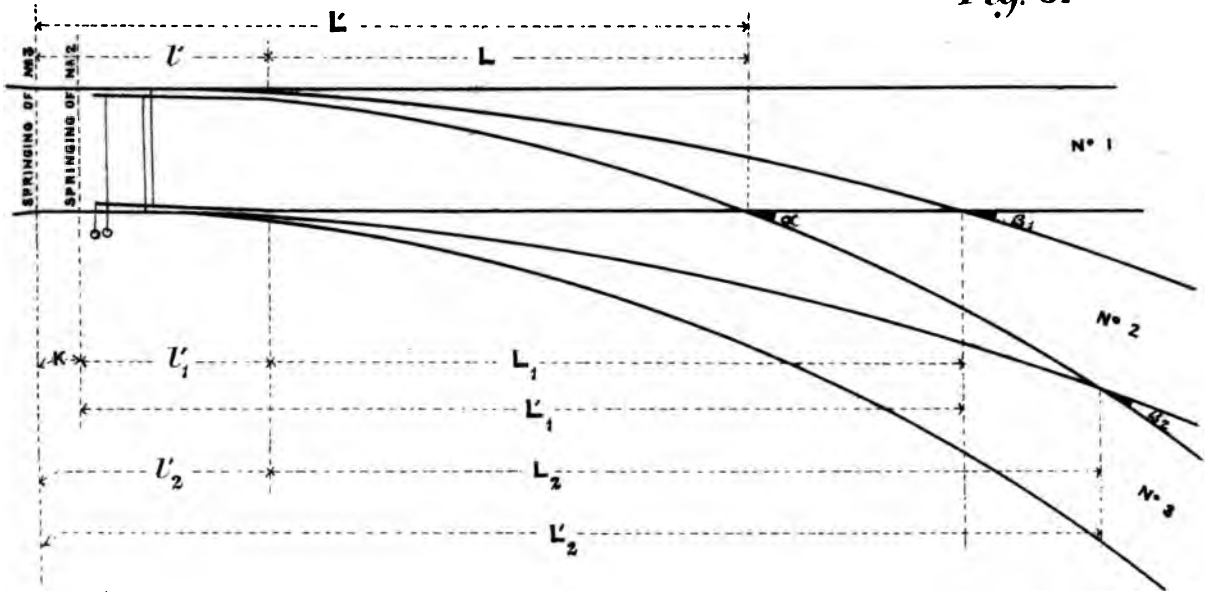

L′
K
K
HEEL
HEEL
SPRINGING
SPRINGING
N° 1
N° 2
N° 3
G
s
S
α1
α
β1
β2

Fig. 30

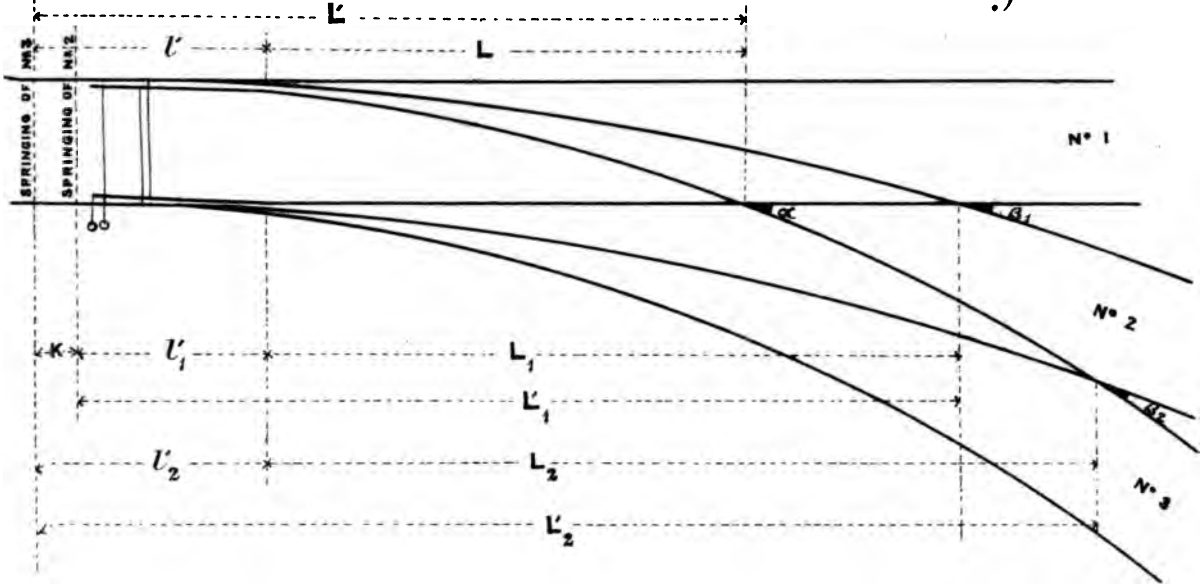
THREE—THROW

Fig. 31



THREE—THROW

Fig. 31



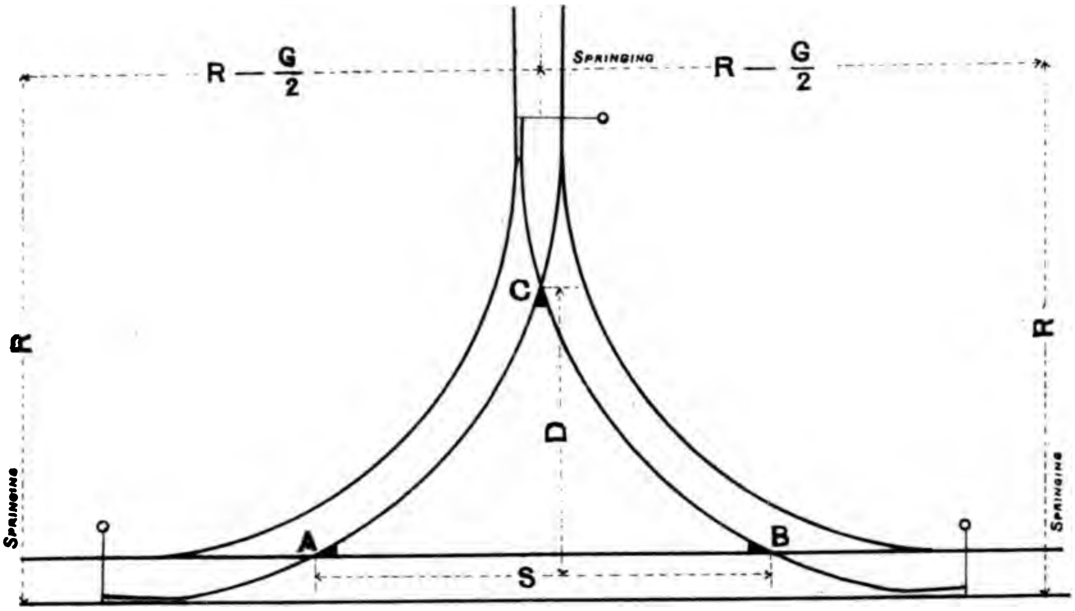


Fig. 32

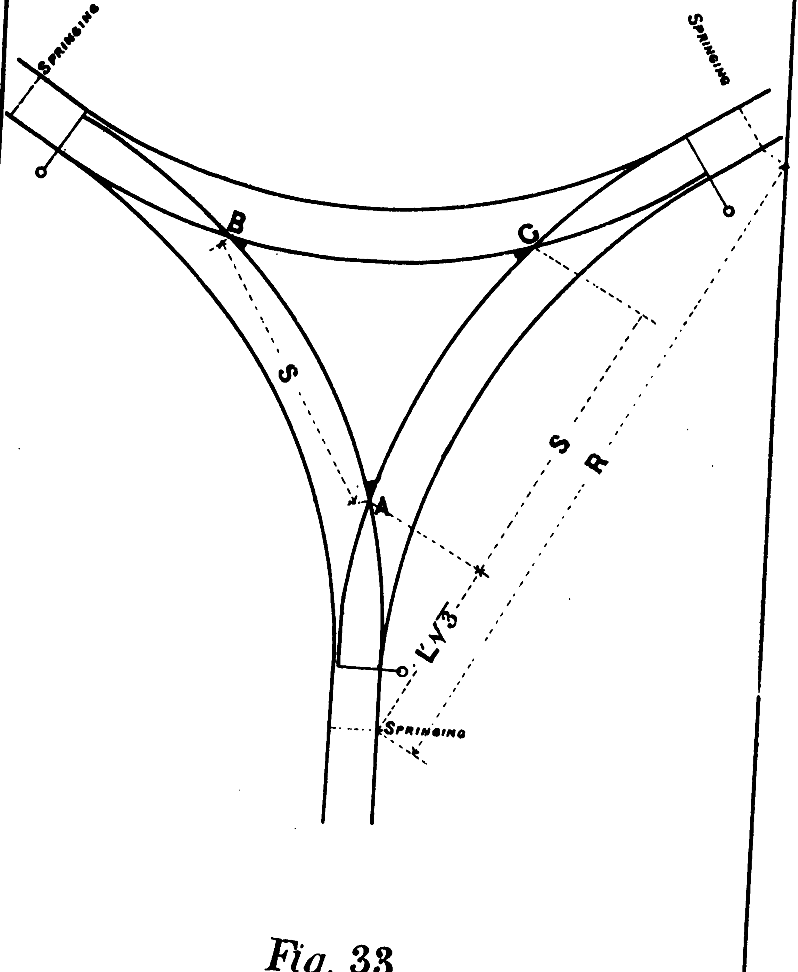


Fig. 33

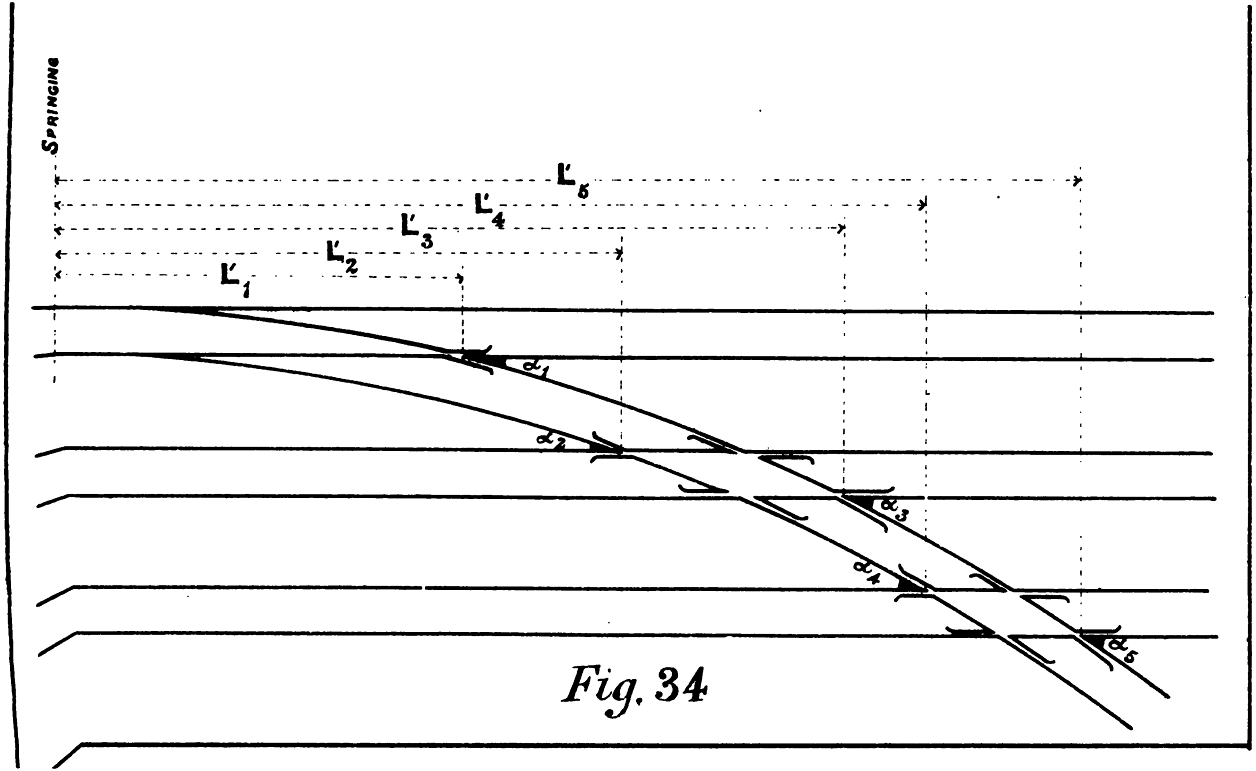


Fig. 34

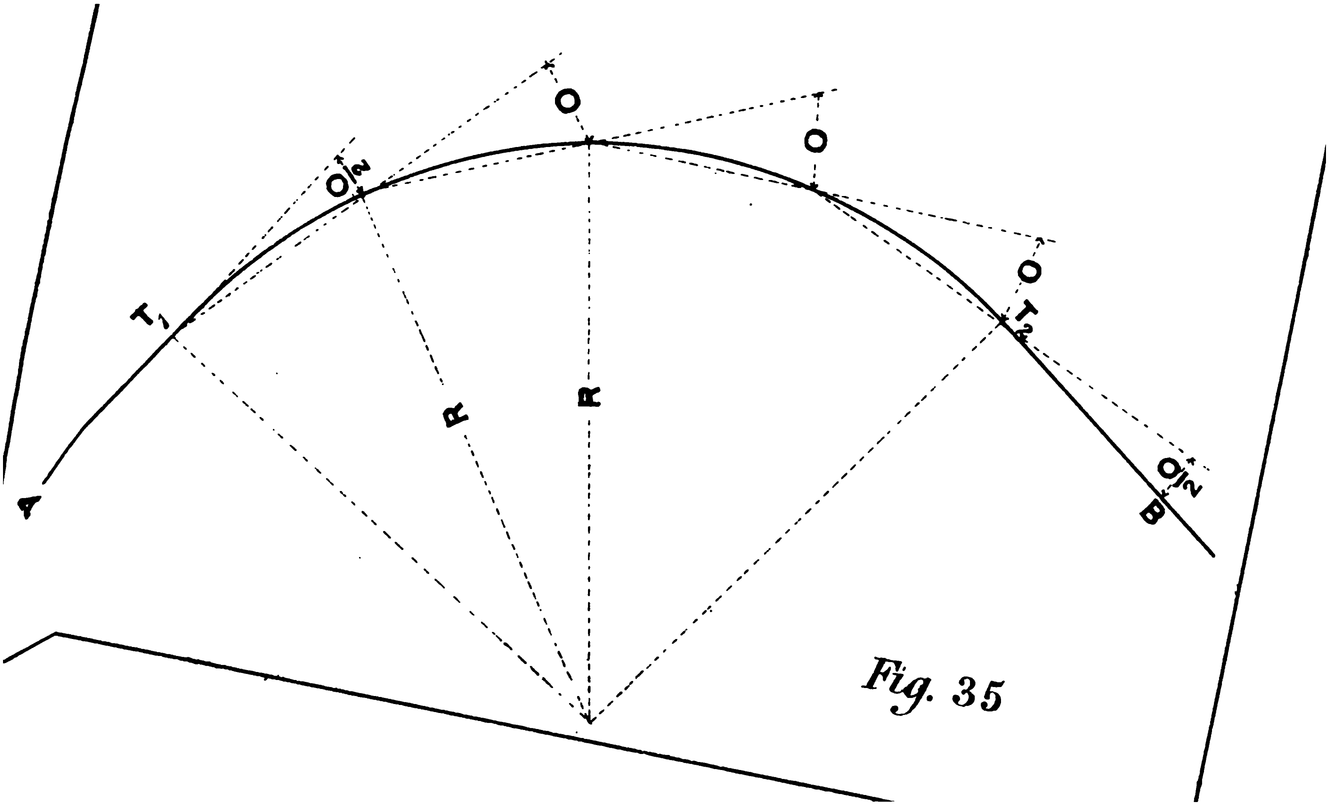


Fig. 35

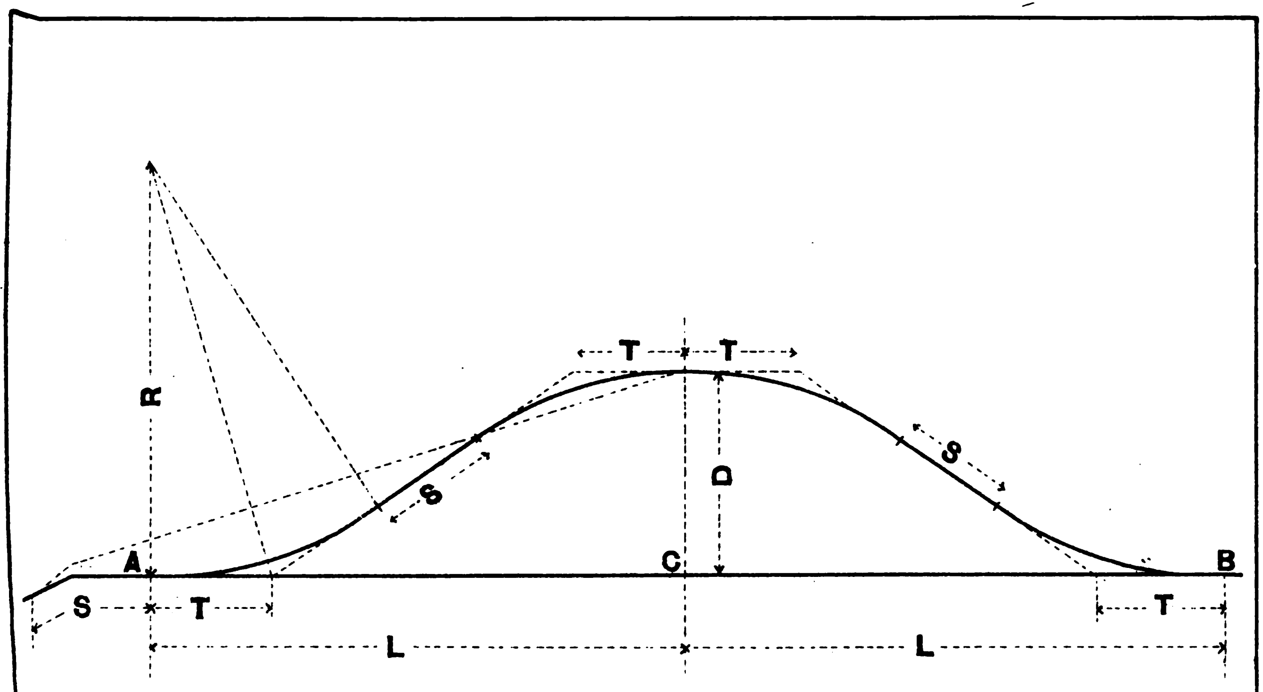
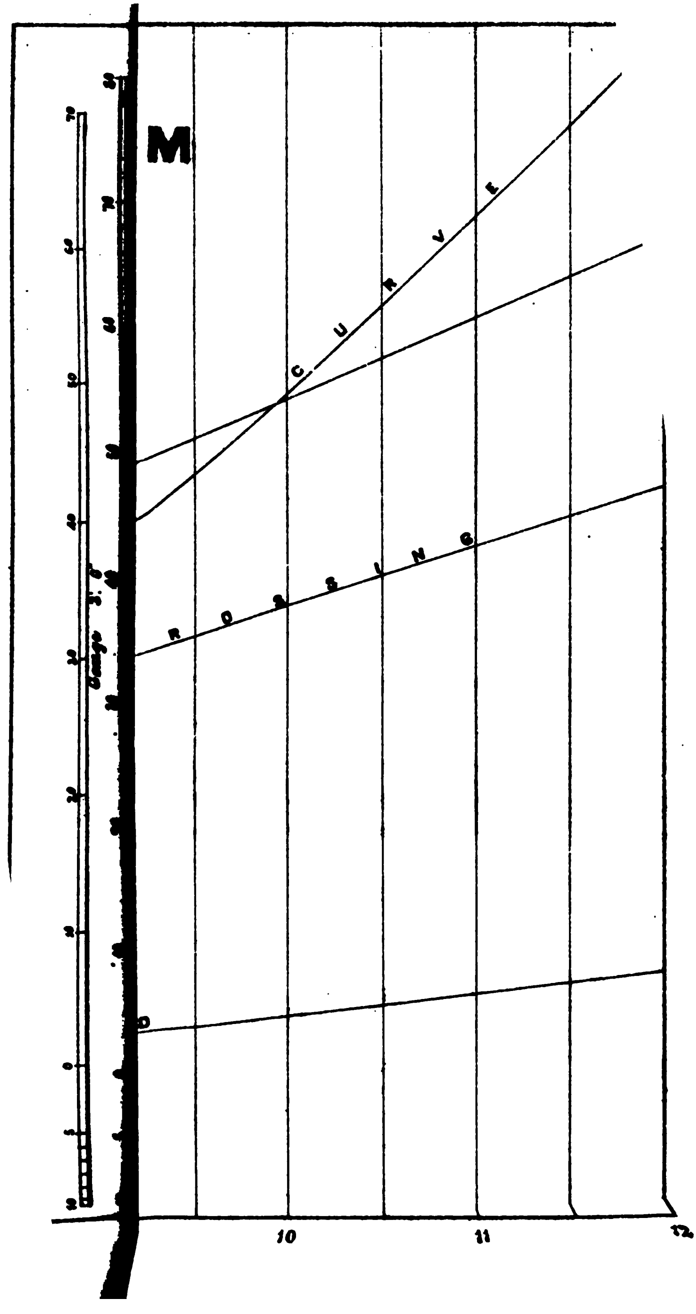


Fig. 36


M
CURVE
ROSSING
D
10
11
12

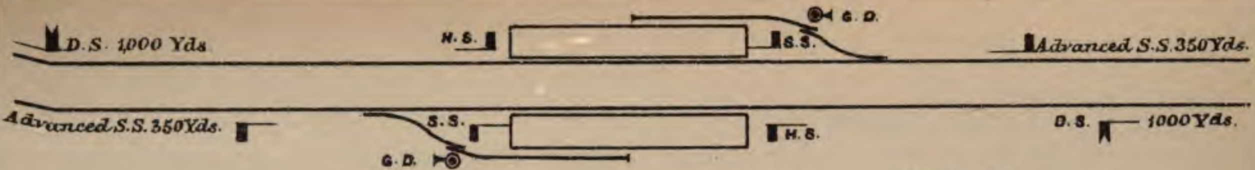


Fig. 38

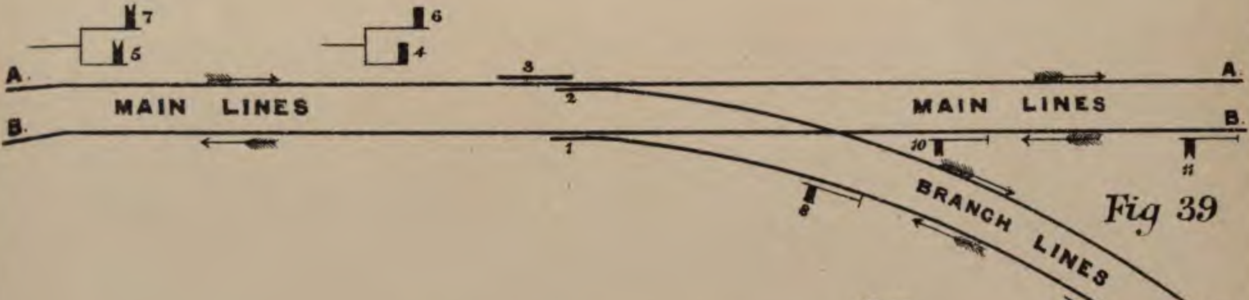


Fig 39

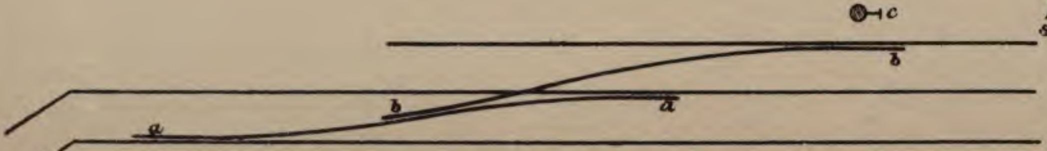


Fig. 40

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